The University of Chicago

The Vertical-Horizontal Illusion

An Experimental Study of Meridional Disparities in the Visual Field

A DISSERTATION

SUBMITTED TO THE FACULTY

OF THE

GRADUATE SCHOOL OF ARTS AND LITERATURE

IN CANDIDACY FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

(DEPARTMENT OF PSYCHOLOGY)

BY

SARAH MARGARET RITTER

1916

Published as No. 101 of the Psychological Monographs

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ACKNOWLEDGMENTS

The experiments described in this paper were performed in the Psychological Laboratory of the University of Chicago during five quarters of the years 1911 and 1912. The work was an outgrowth of a class problem undertaken in connection with a lecture course by Professor H. A. Carr upon Visual Space Perception.

The writer is lastingly grateful to the faithful subjects named within, and especially to Dean James R. Angell and Professor Carr who served not only as subjects but as faithful, patient critics as well. Thanks are due also to Professor Lightner Witmer and to Messrs. Ginn & Company for the use of the cut on page 11.

Chicago, 1915.

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INTRODUCTION

The overestimation of a vertical distance when compared with a similar horizontal extent has been a topic of scientific discussion for more than sixty years.[1] It doubtless has been a familiar error of the school rooms from the beginning of geometrical drawings and long a matter of household familiarity with persons interested in the form and size of objects. To painters and architects the effects of this and similar illusions are well known. The psychologist is interested in these phenomena because of their connection with the entire problem of visual space perception.

The basis of this investigation is a comparison of eight radii of a circular field for the purpose of determining how much each may require to be lengthened or shortened in order that all shall appear equal. The right horizontal line is usually the norm of comparison. The subjective difference between it and an equal vertical line in the upper field is a type of the phenomenon above referred to and the starting point of this study. (See diagram, Figure 1.) There are three groups of experiments based upon the following questions: (1) Is the vertical-horizontal illusion an isolated phenomenon in the field of vision or one of a series of radial inequalities? (2) Are these, in turn, distinct in themselves, or connected with the still wider group of foveal-peripheral disparities? (3) What effect upon the magnitude of any or all of these phenomena will result from controlled variation of certain conditions assumed by various investigators as causal to the vertical-horizontal illusion? Finally, there remains the task of

Fig. 1.

[1] Apparently the first mention is by J. J. Oppel: Jahresbericht des physikalischen Vereins zu Frankfurt am Main, 1854-5, S. 37; 1856-7, S. 47; 1860-1, S. 26.

critically examining the evidence pointing to an anatomical basis for the illusions in question.

If the series of radial differences should be found to vary together, in response to the same changes of conditions, then it is safe to assume that all are a part of the same general phenomenon and that whatever theory is offered in explanation of the vertical-horizontal illusion must be sufficient in breadth to cover the entire series of disparities.

The experiment connects, then, with previous investigations not alone of the vertical-horizontal illusion, but with all those studies in which spacial estimation in one part of the visual field has been compared with that of any other part. These investigations are numerous and varied—extending over the past six decades—and show a wide variation as to both factual and theoretical conclusions. There is a difference of opinion as to whether we see the right field larger than the left, either with both eyes or with one; also, even, as to the comparative values of the upper and lower fields; but the agreement is practically universal that a vertical extent is estimated as greater than an objectively equal horizontal extent.

The theoretical explanations of the different investigators may be grouped conveniently according to two broad types of causes ascribed: *first,* asymmetries of the visual organ, whether of retinal formation, of eye curvature, or of muscular arrangement; *second,* erroneous central functioning, or misjudgments due to ideas of perspective, the influence of contour, contrast, or some more subtle idea entering into the perceptual interpretation. Combinations of cross threads from the two groups of explanatory material may be found; but in the main we are told, on the one hand, that the falsity is in the sense element solely, on the other, that the sense impression *per se* is perfect (that is, in correspondence with objective facts) and the error is one of judgment.

The array of contradictory results and opposed opinions invites sufficiently to further experimentation. There is a possibility that by a method similar to, but differing slightly from, those formerly used it may be shown that methodology has had

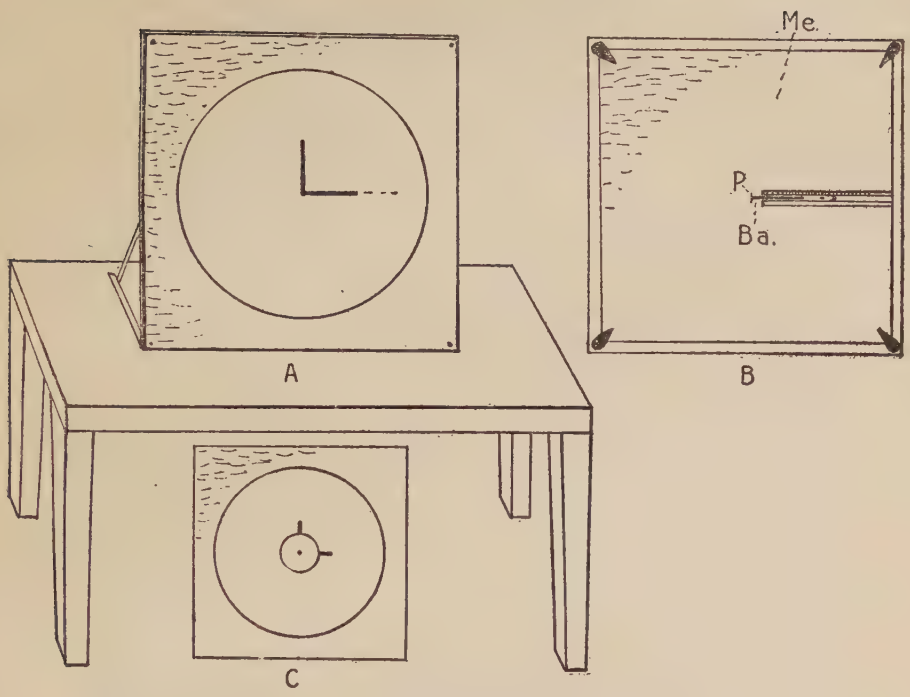


FIGURE 2.—A, front view of apparatus, with the vertical bar as the fixed standard and the horizontal (an extension of *Ba.* in Fig. B) as the variable line.—B, rear view, showing detachable metallic plate (Me.) in frame; also perforation (P) through which the bar (Ba.) passes to the front, to form the horizontal line at the right in A.—C, Same as A, with typical disc as used in Part II of the experiment.

something to do with the great variety of "facts" reported. Or, again, if it is found that by one method of procedure different subjects yield widely differing types of results, it may reasonably be inferred that a measure of the contradictions in reported "facts" is chargeable to individual peculiarities of the observers serving in the different investigations. None of these things could fail to assist in an analysis of existing theories or in pointing a way to a final understanding of the fundamental causes of certain of our illusions in visual space.

The definite aspects of the present problem will be stated in turn in connection with each experimental division.

Apparatus.—The final form of apparatus used was a device of Professor Carr's. (See Fig. 2.) A metal sheet, fixed in

an upright wooden frame 84 cm. square, supported a white background of cardboard, against which were exhibited two blackened steel bars 7 mm. in width. The "standard" bar was detachable. The other, or "variable," entered through a slit at the center from the rear of the metal sheet, where it was attached to a slide and, by means of the slide, to a Vernier scale the readings of which were accurate to 0.1 mm. The front of the apparatus was covered by a glass, fastened in the frame. This served to keep the cardboard and metal bars in a smooth, unified surface. The outline of the white field was modified by a gray cardboard mat, attached to the frame by thumb tacks. From the center of the mat any desired form was cut. Except where other figures are specified, the central field was uniformly a circle 68 cm. in diameter. The subject's head was supported by a mouth-bit rest. The apparatus stood upright upon a table, the center of the field being 129 cm. directly in front of the observer's eyes. The operator was concealed at the rear of the apparatus.

There were four possible positions for the adjustable line, or bar, namely, upon the right and left horizontal and the upper and lower vertical meridians. In the "norm" position, the operator found the Vernier scale and slide at her right hand (Fig. 2, B), and thus the variable bar was thrust through to what to the subject was the right horizontal line. (Fig. 2, A.) By turning the apparatus 90°, 180°, and 270° in the frame the other positions of the variable line were obtained. The meridional changes for the detachable standard had a wider range. A perforation at the end of the bar slipped over a small brass pin at the center of the field (just at the edge of the slit through which the adjustable entered). To the "free" end, on its under surface, was soldered a tiny metal point or pin which pricked into the cardboard and so held the bar in any desired meridian. For convenience the word meridian will be abbreviated to M. and the lines used will be named numerically, by their angular distance above or below the right horizontal, those below being primed. (See Fig. 3.) Thus, M 0 is the right horizontal meridian itself, M 180 is the line opposite, M 90′ is the lower

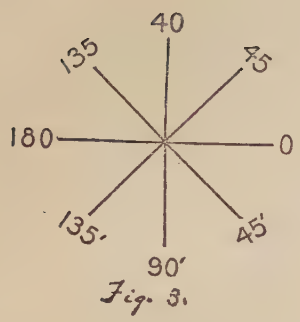


Fig. 3.

vertical, etc. Also for convenience the variable and standard bars will be called "lines," abbreviated to Var. and St., respectively, and referred to by their length. Thus "St. 160" or "line 160" will mean the standard *bar* of that length. In width these bars or lines were uniformly 7 mm., an arbitrary choice made because of the clear, distinct impression and the slight tax upon the attention.

The variable line had a range in length from a minimum of 10 mm. with the shortest standards to 295 mm. for the longest. The standard lines used ranged from 22.5 mm. to 260 mm. in length. That adopted as the normal was 140 mm. The visual angles subtended ranged from 1° 19′ for the shortest St. to 11° 24′ for the longest, and 6° 12′ for the normal St. The corresponding retinal images were as follows: shortest, .28 mm.; longest, 3.2 mm.; normal, 1.7 mm. The norms for length as well as width were chosen after preliminary tests.

Throughout the work of experimentation artificial lights were used, since they afforded greater constancy than could be expected from the sun. Two eight-candle power electric lights, with ground glass bulbs, screened in green, were placed one on each side of the subject and directed toward the apparatus. The room previously had been used for a dark room and all outside light was easily excluded.

Method.—Throughout the experiment there was one constant, apparently simple, problem for the observer, namely, to compare one fixed standard line with one variable line and to judge when the two were equal. It was therefore possible to have one general method of procedure. But the selection of that method was not a simple matter. There were the questions: Should the observer make the adjustments himself or not, and why? If the experimenter made them, should the method be that of "right and wrong cases" or of "minimal changes", and why? Each procedure offered some advantages, but notable disadvantages as well. A brief test of each was made in a preliminary series.

Errata

1. The upper vertical line of Fig. 3 should be marked 90, not 40.

The *method of minimal changes,* or least perceptible differences, had a promise of great accuracy, but proved tedious and taxing. Both the retina and the eye muscles fatigue readily with long fixation, and the judgment wavers with deliberation. Thus three possible causal factors were disturbed and complicated by the method itself. It is therefore not surprising that observers were confused and remarked that the entire figure seemed at times to change enormously in size. The *method of right and wrong* cases promised speed, but again carried its own illusions. The effect of contrast was so apparent, even with moderately small changes in the Var., that the operator gave up the plan, although the observer was unaware of the disturbing factors. There was left the *method of production,* or mean error. This would require less time than minimal changes and avoid irregularities of judgment due to such sudden contrasts as occurred with right and wrong cases. There were, however, aside from mechanical difficulties, these disadvantages in the subject's making his own adjustments—an added probability of his giving more direct attention to one line than to the other, and the further possibility that through the use of his hand the kinaesthetic space sense would unite with the visual estimations in forming his judgments. A *combination method* was finally decided upon, in which the process was that of *production* or *average error,* but with this alteration, namely, that the observer —who maintained fixation at the center of the field—dictated the adjustments, which were made by the operator.

The *order of procedure* in these adjustments may be made clear by taking a typical case, in which, for instance, the St. was at M 90 and the Var. at M 0. The two-line figure was presented with the Var. at its minimum length for the given St. The subject, who had fixated the small brass pin at the point of juncture of the two lines, answered, for example, "Move out four centimeters," "Now one centimeter," "Now two millimeters," "Now a tiny bit more, less than a millimeter," "There!" If he found at any time that he had gone too far no record was made and a new start was taken. After each response, while waiting for the adjustment and the operator's "Ready," the subject

rested his eyes about 5 cm. below, or at the outside of, the angle. Ample time was allowed for a refixation in each case before a new adjustment was dictated. When the final judgment of equality was reached and recorded, the Var. was then pushed out somewhere near its maximum length and adjustments were similarly made in the reverse direction. From six to a dozen settings of the Var. were generally required in reaching a judgment of "equal." The subjects varied in this respect, some moving rapidly by long steps, others more slowly and deliberately. As a rule the rapid work was more consistent, though deliberation, *with method,* had fair success. As an example of the latter, subject Ca. stated when the work was completed that before giving a final judgment of equality in any case, he always closed his eyes for an instant and came back for a fresh look at the figure.

The adjustments continued, alternately, from greater to equality ("In" series) and from less to equality ("Out" series) until five judgments each way, or a total of ten for each pair of lines, were obtained. The order of presenting the Standards—supposing the Var. to be at M 0—was as follows: M 90, M 90′, M 45, M 45′, M 135, M 135′, M 180. (For other positions of the Var. the same angular relationship of the two lines was adhered to.) This complete circuit—once around the field in any given case—constitutes what will be termed a "single series." It was followed in every case by another "single series" in the reverse order of St. positions, and the two combined make what is termed a "double series." The averaging together of such a double series, as was done to obtain the majority of the tables and graphs, was for the purpose of eliminating the possibility of influence from the chance order of procedure upon estimations of successive lines, as well as to insure that a sufficient quantity of data entered into each average. In obtaining the data for the single series the judgments of the original "In" and "Out" series were first averaged separately and these results averaged together. (See Table VI.) This procedure made it possible, first, to scrutinize the effect of the direction of the adjustment, then in a measure to eliminate this influence—by the method of

averaging. Again, the double series with any one position of the Var. line was followed by such a series with each of the other possible positions of this line. By the averaging together of the four sets of data in which the influence of the adjustment factor was made to play against itself in two pairs of opposed directions, it was hoped to obtain a fair elimination of whatever disturbance arose from this source. Furthermore, an attempt was made from the beginning to forestall this influence of adjustment, or of objective movement, by having the judgments made only when the lines were stationary, by the subject removing his eyes while the adjustments were being made, and by his having ample time for a refixation after each signal of "Ready." Such are the main features in the order of procedure. Cues were avoided (1) by having different starting points for successive series in either direction, thereby breaking up the tendency to estimate "equality" by counting the "steps"; also (2) by the experimenter's being hidden and maintaining a monotone in giving signals. During rests conversation upon indifferent subjects was freely indulged. This was expected to interfere with memory cues and lead the subject to return for each judgment to the original sensory 'given.'

Certain features were standardized. In the procedure described above effort was made to preserve a uniformity in the observer's bodily and ocular position and in his attention attitude, since lack of control in these matters may be partially responsible for variations in the results of certain former investigations.—The subject was seated comfortably before a narrow table upon which the arms could rest. The table was fastened to the floor and to it was firmly attached the mouth-bit head rest. A constant position of the head aided in preserving a uniform balance of the ocular muscles, and, together with the unvarying fixation (with eyes in the "primary" position) of the center of the objective field, insured a fair uniformity of the retinal area explored. Furthermore, the subject was directed to attend mainly toward the standard, and report when the variable was too long or too short with respect to it. In brief, norms were established for all those conditions which were to be altered in the course of the experiment. Summarized, these norms are given below.

Normal Series.—(1) *Bodily Attitude:* Subject seated, eyes looking directly forward to center of apparatus; binocular fixation, eyes in the "primary" position; head position maintained by mouth-bit rest. (2) *Mental Attitude:* Attention directed mainly toward the St., the Var. to be estimated as too long or too short by comparison with it. (3) *The apparatus:* Circular field, radius 34 cm.; standard 140 mm. in length; order of presentation of standard—M 90, M 90′, M 45, M 45′, M 135, M 135′, M 180, then the reverse; position of the Var., M 0 (followed in "norm variation" series by the positions, M 180, M 90′, M 90); distance of the center of the field from the subject's eyes, 129 cm. (length of *retinal image* and size of *visual angle* formed by the normal St., 1.73 mm. and 6° 12′ respectively); (4) Lighting conditions of the field, uniform and constant.

Each of these conditions, with the exception of distance of the field from the eyes, and the meridional order of presentation of the St., was at some time in the course of the work made the central feature of investigation, and hence was varied singly while all other conditions remained constant. These variations will be described when the separate problems are discussed; but for all reference to a "normal" series, the above conditions are to be understood.

Perfection is not claimed for the method adopted. It is hoped that there is an elimination of the grosser errors involved in minimal changes and right and wrong cases, and a retention of the best features of the method of average error. All disadvantages of the latter are not ruled out; neither, it is believed, are they augmented in any way, while there is the one clear gain in not having the subject make his own adjustments. The defects of a method, if measurable in their effects and not destructive of the purpose of the experiment, may, in their turn, serve well in final interpretations. This is to be remarked of the influence of the adjustment factor, noticeable in this work and in that of all others who have used the method of mean error. If it is thought that even with the above precautions the prejudices of the operator may have influenced the results of her subjects

as a consequence of her having manipulated the apparatus, let it be said that none could be more surprised by the outcome of the experiment than the operator herself. The results, in fact, were not carefully evaluated until some time after the experiment was completed. There is sufficient individual variety, moreover, to guarantee that no one person's influence could have been responsible.

Subjects. The subjects serving regularly in this experiment were a professor and nine graduate students in the department of psychology. They were Professor H. A. Carr, Doctors W. S. Hunter, F. A. C. Perrin, R. B. Owens, Messrs. E. S. Jones, G. W. Kirn, J. O. Pyle, M. O. Beanblossom, Miss Katherine Taylor[2], and Mrs. L. A. Barr. All knew more or less of the vertical-horizontal illusion and that it was a feature of the experiment. None knew his results from day to day or the occasion of the special changes in the program. The instruction given to each was that he should endeavor to maintain a naïve attitude and seek to base his judgments upon original sense impressions and not upon deliberative estimations intended to balance an anticipated error. All subjects had had training in experimental psychology and hence realized the importance of fulfilling carefully the conditions. It is the writer's grateful opinion that no group would or could give greater effort to reporting faithfully what was *seen* or *sensed* rather than what was calculated to be true. However, two subjects, Be. and O., found it impossible to discard the central factors—the former measuring by the number of "steps," the latter by collapsing angles, etc. Their average variations were higher and their total results less consistent than those of any other subjects, and it was therefore necessary to substitute other observers in their places.

The total number of complete or abridged series served by each subject was as follows: Be., 21; O., 7; Ca., 34; Pe., 33; Ba., 54; Py., 64; Ki., 70; Ta., 34; Jo., 53; Hu., 62; a total of 28,540 judgments. This does not include preliminary tests made without apparatus nor certain supplementary series in which additional subjects (Po., S., A. R. C., T. J. C., J. R. A. and others) served for a brief time.

[2] Deceased.

THE NORMAL VISUAL FIELD

The shape of the binocular field, because of the position of the eyes in the sockets, is objectively an oval. Whether this objective oval appears subjectively as such is a question. It might appear as a circle or as some other figure.[1] If it were objectively a real circle it might appear, again, as an oval. There is a possibility that the vertical-horizontal illusion may have either a correcting or a distorting effect upon the entire outline. But the whole field of vision can scarcely be subjected to the tests of this experiment. A limited portion, extending from the focus as far into the margin as practicable[2] in binocular vision, is here made the object of research. The determination of the subjective appearance of a real circle, based upon the estimations of the length of eight objectively equal radial lines, is the first problem with each observer. The subjective form outlined by the intercomparison of these radii, while the center is fixated and other conditions are "normal," is what is termed in this paper the "normal visual field."

The question may take one of two forms: first, what must be the actual character of a set of radiating lines or meridians that they may appear as radii of a circle, their common point being fixated; second, what is the subjective appearance of a set

[1] The approximate form of the actual figure when the entire field is attended to for experimental purposes is given by Witmer in the following figure. The problem of this paper falls well within the central area of binocular vision.

FIGURE 4—From Witmer's Analytical Psychology, p. 52. (Reduced.)

[2] The actual extent of the circular area was determined by the selection as the norm of a standard length which afforded the longest radii the subjects could grasp with any feeling of surety in estimations.

of equal radiating lines? The answer of the first aids in a determination of the second, which is the final object of the quest. The vertical-horizontal aspect of such a field is the matter of crucial interest in the investigation. Within the scope of this "normal" area are smaller concentric, or zonal, sections, centrally and marginally placed, which are likewise to be explored for typical aspects of the disparities found in the first survey. This makes up the second problem group. If for individuals or groups of individuals there develops through a long series of "normal" and "supplementary" tests a persistent *type field,* there remains finally the larger problem of explanation. This will occupy the third section of the experiments, and involve also a final critical examination of retinal conditions and a summary of theoretical data.

As indicated in the introduction, the literature of the earlier investigations would lead to great uncertainty of expectation in regard to the "field types," or outline forms. There is a fair agreement that the difference is greater between the vertical and horizontal dimensions than between any other lines of the field; otherwise, there is more diversity of opinion. According to Delboeuf[3] the elongation of the upper vertical is greater than that of the lower. If Fischer's[4] results are typical, the reverse is true.

Again, according to Kundt,[5] with binocular vision the right and left halves of the field should be nicely balanced, because each eye overestimates its outer field. Münsterberg[6] assures us that the left field is larger than the right, and that only under certain conditions is a vertical line exaggerated with respect to an horizontal. Stevens,[7] on the other hand, says not only is the upper vertical usually greater than both the lower vertical and the right and left horizontal dimensions, but the whole right field is phenomenally larger than the left; also that the periphery

[3] Bulletins de l'Académie Royale des Sciences de Belgique, 2, XIX, p. 195. 1865.

[4] Archiv für Ophthalmologie XXXVII, 1, S. 97-102; 3, S. 55. 1891.

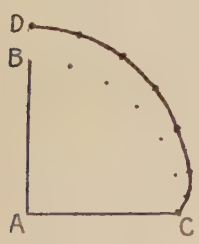
[5] Poggendorff's Annalen der Physik und Chemie, CXX, 118. 1863.

[6] Beiträge zur Experimentellen Psychologie, H. 1, S. 126. 1889.

[7] Psychological Review, Vol. XV, p. 69; Vol. XIX, p. 1.

is overestimated with respect to the foveal parts. Certain statements of James,[8] and also of Fischer, would indicate an opposite foveal-peripheral relationship. Wundt,[9] after years of investigation of his own and on the authority of others also, states that with monocular vision the outer or temporal field (viewed by the nasal side of the retina) is overestimated with respect to the inner field by about 1/40; that the upper vertical extent is overestimated with respect to the lower vertical by 1/16, and with respect to an equal horizontal line by about 1/7 to 1/10 or 1/20.

There is, however, an earlier piece of work by Wundt[10] that is of significance here. A double test was made in the following manner. First a standard distance of 20 mm. was marked off by two points upon a vertical, then upon a horizontal, line, and in each case a pair of compasses was so adjusted that one end rested upon one of the dots and the other was extended to an apparently equal distance with the standard but in line successively with the angular directions given below. Second, the standard was placed successively upon the other meridians and an equal extent was estimated (a) upon the vertical, then (b) upon the horizontal line. The data for the last named case is given below, and by extending each line the amount it was overestimated in terms of the horizontal the writer of this paper has cast the same into the form of a graph. (Fig. 5.)



Angular distance from the horizontal.	Horizontal estimated distances.
0°	20 mm.
15°	22
30°	22.5
45°	23.5
60°	24
75°	24.5
90°	25

Fig. 5.

A 90° rotation to the right or to the left may be necessary to convince the reader that the line CB of Figure 5 is an arc of a

[8] Psychology, Vol. II, p. 140.

[9] Die Geometrisch-optischen Täuschungen, S. 106. 1898. Outlines of Psychology (Judd), p. 136.

[10] Zeitschrift für Rationelle Medicin, 3 B. VII, S. 374. 1859; also Beiträge zur Theorie der Sinneswahrnehmung, S. 158. 1862.

circle. It must be borne in mind also that each of the indicated radii was compared singly with the horizontal standard; that is, the comparison of the lines was made in pairs, not in groups.—The meaning of the graph is that in Wundt's comparison of seven radii in a single quarter of a circular field the increasing over-estimations of the lines as they approach the vertical inclination to the base produce subjectively a form resembling in the main a quarter of an upright oval, and the vertical itself is seen greater than the horizontal in the ratio of 25:20, or one-fourth larger. The bulging of the lines, however, begins *noticeably* with the first angular remove from the horizontal base, and in order that this segment of the field should appear as a quarter of a circle there would be required a gradual flattening, increasing toward the poles.

Granting that such should be the true outline of our subjective apprehension of a circular form, we would never be conscious of it in our ordinary vision. What we see (or estimate) as a circle on a plain wall before us may have radii of greatly varying objective lengths, but we do not know it. And in the drawing of a circle objective measurements and eye movements to various parts of the outline serve to correct our judgments. Wundt says the vertical-horizontal illusion is not apparent in the drawn circle; though others (e. g., Holtz[11]) say a circle drawn freehand is flattened at the poles, which would indicate that a real circle has subjectively a polar eccentricity similar in kind if not in degree to that of the above graph. The inference would be that the objective oval of our entire visual field, which is elongated horizontally, tends to bend itself toward the circular form. But Wundt did not extend his figure to so wide an application. And we are not at present concerned further with the inquiry as to the whole field, but rather with the factual relations within the scope of that area that is the basis of the present study.

PART I. TYPE FORMS: MERIDIONAL DISPARITIES

The first division of the tests is intended to answer the first of the questions mentioned in the introduction, i. e., what in the case of each observer is the subjective impression of a circular

[11] Wiedermann's Annalen der Physik und Chemie, X, S. 158. 1880.

form, as determined by the comparison, in pairs, of eight radii of this form? There are two sections: first, the "norm" series, with its variations; second, a supplementary series, intended to verify the results of the norm work and to add certain data of some intrinsic interest. All have reference to the general outline or *type form of the field* as controlled by subjective disparities in the radial lengths.

1. *The "Norm" Type; Norm Variations; and "Primary" Types*

The definite questions of this section are: (1) Given a standard line of 140 mm. at M 90, what will be the length of an apparently equal line at M 0? Given the same standard successively upon six other meridians (Fig. 3), what in each case will be the length of an apparently equal line at M 0? (2) By changing the position of the Var. successively from M 0 to M 180, M 90′, and M 90, and repeating the comparisons, what changes take place in the comparative lengths of the meridional extents? (3) Is there any harmony among all the series upon which may be based a conclusion as to the differences of spacial estimation in the meridians investigated; if so, what is the position of the vertical-horizontal illusion in the series of meridional differences; and what is the final form of the subjective field? Questions 1 and 2 are answered experimentally and the data given in the tables. The answer to the reverse of these questions —i. e., what is the apparent length of the St. in each case when the Var. is objectively equal thereto?—is approximated by transposing the added length from the Var. to the St., as is done in the graphs. This makes possible the intercomparison of all the radii, with the Var. at 140 mm. as the basis of estimation. The answer to the third question is based upon careful comparison and averaging of the data, as explained below.

These tests were preceded in the case of each subject by a preliminary series in which was gained a familiarity with the general task, both as to its objective procedure and its subjective attitude. Those results were discarded. The data finally retained are divided for description into three series, namely:—

(1) *The "Norm" Series,* which follows the procedure described as the normal (page 9), and from which is derived what is

termed, accordingly, the *"Norm Type"* of visual field. (Series A and A′, Chart I and Table I.)

(2) *The "Norm Variation" Series*—involving only the changes in the position of the Variable line, and producing three series of graphs. (Series B, C, and D, Chart I and Table I.)

(3) *The Combination, or Primary, Series*—a set of data obtained by averaging together the "Norm" series and its variations, the purpose of which was to eliminate whatever peculiarities might have accrued from the influence of the factor of adjustment. This gives what may be termed the real "Normal," or the *"Primary" Field Type.* (Series E, Chart I and Table I.)

Between the first and the second parts of the above the amount of practice intervening varied with different groups of observers, as will be noted in connection with the results.

Results.

Two deflecting or secondary influences entered more or less prominently into the work of this and other sections, namely, the subjective one of *practice* and the mechanical factor of *adjustment* in the lines. Both were necessary evils which in the end may turn to good account. Each will be discussed in a later section, hence in this place only their more evident effects will be pointed out. For the matter of average variations within a series reference is made to Table VI, where typical aspects are given. Work that showed large discrepancies in this respect was discarded, and only that which is believed to be reliable is reported.

In all descriptions of results two sets of features, then, will be followed through, namely, those that are permanent or common—common to a long series of the same individual's work, common perhaps to the work of a group or groups of individuals —and dependent presumably upon a cause fundamental and primary in ocular conditions; second, those which may be transient, and hence attributable to some, evident or obscure, secondary factor.

In summarized details the results of this section are found in Chart I and Table I. The following paragraphs describe the principal facts there shown in each subject's work.

Subject Jo.

Series A—For this subject, as for all others who served regularly, graph A (Chart I) represents practically the first normal series. Its most notable feature is the fact that the lower field (M's 90′, 45′ and 135′) is in every case markedly larger than the corresponding upper parts. The left field is also larger than the corresponding right, except that the right upper diagonal, M 45, is *slightly* greater than the left upper diagonal, M 135. The right horizontal, M 0, occupies the eighth place in order of size, the lower vertical the first. The line holding the seventh place, i. e., nearest equal to the right horizontal or Var., is the opposite line, M 180.

Series A′.—The 43rd series for this observer. It is selected here because of its proximity to series B. Practice has resulted in a notable vertical lengthening of the field, with a persistence of the exaggerations of the under and left halves over their respective opposites. In other words, while practice increases all the meridional disparities, it most affects the V-H difference.

Series B.—With the Var. at the left (M 180), there is a shortening of the lines at angles *a* and *a′* and a corresponding lengthening at *c* and *c′* (the opposite field from the Var.), while the right horizontal line also becomes slightly longer than the left.

The persistent features carried over from the norm are the extreme vertical length of the field, and the overestimation of the lower half with respect to the corresponding upper portions—excepting only the case of M 135′ (angle *a′*). The overestimation of the right field in graph B is *less* than that of the left field in graph A′. This indicates that, barring the disturbing factor of mechanical adjustment (of the Var.) the left half would still appear greater than the right.

Series C.—With the vertical position of the Var. (M 90′ in this case) the field assumes more uniform proportions. A tendency to *push out* or exaggerate the field opposite the Var. is apparent again, resulting now in an enlargement of the upper field over the lower, or a reversal of the usual norm type.

The horizontal lines and the lower diagonals are *underestimated* with respect to the lower vertical, or Var. This is a feature persisting from the norm type and is common to the B series also. The underestimation of the right horizontal is greater than that of the left horizontal. This also accords with anticipation from the norm data. The right diagonals, however, agree better with the B than with the A′ series. The overestimation of both the upper and the lower vertical extents with respect to each of

the horizontal meridians remains prominent, though with a reduction of percentages. (The apparent decrease of the size of the field is due to assuming as the unit of measure the objective rather than the apparent length of M 90′, the line heretofore most greatly exaggerated in the graphs.)

Series D.—With the Var. at the upper vertical (M 90), whatever disturbing factors accompanied it are reversed in their influence from that in graph C. Accordingly, we do find overestimations reappearing in the opposite, or lower, field. The *average* (6.3 mm.) of the overestimations in the lower field in this series is slightly greater than the average (5.3 mm.) overestimation in the upper field in the preceding series C, which is so far an indication that, barring the influence of adjustment, or of angular distance, the lower field in both C and D would appear greater than the upper field. This is *true, provided* the disturbing influence of the Var. is not greater when it occurs in the upper field than when it is in the lower.

All lines in the left half of this field are greater than the corresponding ones in the right (left upper *vs.* right upper, etc.), and this again is consistent with the norm type A′, and especially with A. Again the vertical elongation of the field persists.

Series E.—The averaging of the four series last described gives a graph (E) that not only resembles the norm A, but shows more pronouncedly the upright oval form which has prevailed throughout a long series of intervening practice. It stamps finally what must be deemed an *individual peculiarity,* namely, the *tendency to overestimate the left half of the field with respect to the right and to produce a larger V-H illusion in the lower than in the upper field.*

The problem of validity, of primary and secondary causes, is crucial. Whether or not the apparent characteristics in any case may be referable to a fundamental ocular condition or, instead, are traceable to an acquired habit or attitude, is a question for subsequent sections. Here it may be accepted, in summary for this subject, (1) that graph E is a fair average of the four series (A′, B, C, D) from which it is derived and that in it the immediate effects of adjustment have been eliminated, while (2) the results of *practice,* so evident in A′ and persistent in E, are such as to render doubtful the whole matter of primary estimations in the left field. As to the validity of the differences in the upper

and lower fields it may be said that in the intervening work between the A and A′ data the lower field was overestimated with respect to the upper in 75% of the series. As to the primary character of the vertical lengthening of the entire field there seems no controverting evidence.

Subject Pe.

Series A.—Contrary to Jo., this observer sees the upper meridians larger in every case than the corresponding lower ones. (The difference is not marked and the average variation would bring it into question were it not persistent in the later averages.) In harmony with Jo., but more pronouncedly, he makes the left field greater than the right. The overestimations of the three meridians in that field are greater than the error in either of the vertical lines. The usual V-H illusion for the left side of the field is thereby destroyed, although it is quite prominent on the right side. The upper left diagonal is first in order of size.

Series A′.—The 10th series, but typical of all later. There is noted again the large left field with increasing exaggeration on M 135; a greater difference between the upper and lower fields (favor of the former); also the considerable lengthening of the upper vertical line—which now involves an overestimation with respect to the left horizontal M.

Series B.—With the variable at the left there is marked consistency in underestimating the right horizontal line; in the small average enlargement of the upper field over the lower; in the pronounced V-H illusion for the right field; and in the slightly negative V-H illusion in the left field. The following discrepancies (indicative of a secondary influence both here and in the norm series) are notable: both M 135 and M 135′ (which are now the angles *a* and *a′*) are underestimated with respect to the Var., M 180, whereas they were formerly seen greater than this line; M 45 and M 45′ are each overestimated with respect to both horizontals in this graph; the excess of M 180 over M 0 is reduced one-third, or from 19% in the A′ series to 6.5% in this series.

Series C.—With the Var. at M 90′ there is an underestimation of all other meridians with respect to this line, with the exceptions of M 90 and M 135. The underestimations are greater upon the right side than upon the left, a fact which accords fully with the A and A′ data. The V-H illusion now prevails for both

vertical radii in comparison with either horizontal line.—Apparently the secondary factor producing these variations is here working together with what seems a constant "primary" tendency, to produce a larger overestimation in the upper field than in the lower.

Series D.—With the Var. reversed from the position of Series C the secondary factor presupposed in the above becomes opposed to the "primary" tendency as respects the vertical halves of the field, and proves the stronger. For the first time the lower half is larger than the upper, but the percentage is more than two thirds smaller than for the opposite phenomenon in series C —5.5% as against 18.2%, indicative of the *presence,* at least, of the opposing primary tendency. A further persistent norm trait is the overestimation of the left field with respect to the right in all corresponding M's. The comparison of M 135 with M 45 draws the usual lengthening of the former out of the obscurity into which it is cast by its relation to M 90.

Series E.—The peculiarities of the final ("primary" or "normal") graph are (1) that *the upper field is slightly but consistently larger than the lower,* (2) *that the left is markedly larger than the right,* and (3) *the largest overestimation lies in M 135.* These are all features so consistent with the "norm" type A as to strengthen the inference that the latter minus the effects of the adjustment (eliminated here) would coincide closely with this final graph. All the work of this subject shows unusual consistency, and with very small average variations within the series.

Subject Ta.[1]

This observer was present only for the series A and A′ and the long intervening work that led toward the remaining tests included in this group. Typical data is recorded in Table IV, and the graphs are shown, in connection with "Practice Effects," in Chart V.

Series A and A′ singularly resemble the work of Pe., with an even greater exaggeration of the typical features. There are, for example, the slight predominance of the upper field over the lower, the much greater enlargement of the left over the right, the same unusually large measurements everywhere except

[1] An unsuspected illness took Miss Taylor suddenly away from us, and left the memory of her faithful work saddened by the thought of the effort it must have cost her.

upon the diagonals of the right field, and an especially great prolongation of M 135. There is no apparent reason for this similarity. Pe. was a strong robust man, and did not wear glasses. Ta. was a slight delicate girl, and wore glasses. (Her results, however, were of the same type with or without glasses.) There was no conference whatever between the two observers concerning the work; neither knew the other's results. Each frequently remarked, when the St. was placed upon M 135, that that line looked very, very long, seemed to "stretch out infinitely."

The persistence of the norm type for this subject is seen only in the later "practice" series, A′, where practically the same general outline is preserved, though with greatly enlarged measurements.

Subject Hu.

Series A.—The early, naive work of this subject differs from either of the types described above. His is a third—unique, individual, and peculiar—type of "norm" field. The characteristics are as follows: The right field is larger than the left (contrary to both the preceding); the upper is larger than the lower (in harmony with Pe., contrary to Jo.); there is a tendency to an underestimation of M 90′ and M 135′ (as well as M 180), with respect to the Var., M 0. The V-H illusion, therefore, though prominent in the upper field, does not exist in the lower.

Series A′.—Forty-five series intervened between A and A′, the latter being the 51st for this subject. It is selected here because it is a typical norm series of the group of tests in which series B, C and D occur. Peculiar practice stages (see page 61) had marked the intervening tests since the A series, only the final aspect of which need be noted here.

Graph A′ shows everything underestimated with respect to the Var., M 0. There is a pronounced lengthening of the field horizontally, and flattening vertically, so that the V-H illusion has vanished from the upper field also, so far as the right horizontal line is concerned. It still prevails with respect to M 90 *vs.* M 180, though to a very slight degree—less than 1½%. Nevertheless, the following characteristic features of the "norm" persist: (1) the upper field is greater than the lower; (2) the right field is greater than the left.

Series B.—The graph is practically the same as that of the A′ series, with the exception that line 180 is made the basis of construction. The relative over- and underestimation continue almost in identity, with the exception of a slight shortening of

the *a* and *a′* and a corresponding lengthening of the *c* and *c′* diagonals.

Series C.—Throughout the greater part of Hu.'s work, M 90′, now the Var., held eighth place in the serial order of size. The position is maintained here, i. e., all other lines are overestimated with respect to it. The horizontal lengthening of the field persists. There is again the apparent tendency to lengthen the diagonals opposite the Var. The right field, once more, is larger than the left, the upper than the lower.

Series D.—M 90′ and M 135′, prominently short in all this subject's work, are underestimated. (Compare graphs A, A′ and B.) The entire lower field is smaller than the corresponding upper parts. Again, there is the horizontal length, greater in the right field than in the left.

Series E.—The data for this section (tabulation and graph) is simply an average to be anticipated from the series of which it is composed. The graph, carrying over the idiosyncrasies of practice from long series intervening between the A and A′ data, bears little superficial likeness to the norm A. The original prolate form has become oblate; the V-H illusion is conspicuously absent from all quarters of the field. Unanswerable evidence is this for the presence of some strong *secondary* influence, which does not bear the *usual* marks of the adjustment effects. But the contradictory features are left for a later series to resolve. (See Part III, Sections 4 and 5.) Here the essential facts are these: that in this final "average" graph the upper field is larger than the lower, the right is larger than the left, and there is a marked flattening in the lower left segment—in all of which there is harmony with the norm. Unanswerable evidence is this for the presence of some strong *primary* influence which, back of and superior to shifting secondary forces, predestines the subject to see a given objective field in his own characteristic way, which may differ in particulars from that of any other individual.

For the remaining subjects (Ba., Py., Ki., and Ca., who served only in a brief summer session) there was no long period of practice with but one position of the Var., as in the case of the preceding group. On the contrary, a B, C, and D series followed in succession after every normal series. Practice, then, may be expected to differ in its results. For three of this group of observers these results are shown in the graphs by broken lines, though here the diagonal measurements were inserted on inference, as only the four cardinal meridians were used in the

later series. The pairs of graphs will, in most cases, be discussed together.

Subject Ba.

Series A and A′.—In common with a majority of subjects this individual began her work with an overestimation of all meridians with respect to the Var. (M 0). The M 135 and M 135′ were especially pronounced in their overmeasurements; consequently, the entire left field was greater than the right. In series A the V-H illusion was larger in the lower field than in the upper; the upper and lower diagonals showed slight inconsistency, though as a whole the lower field was greater than the upper. The A′ (16th) series continues with a slight overestimation of M 180, but reverses the differences between M 90 and M 90′. (The diagonal meridians were not measured.)

Series B and B′.—The B series, except in the lengthening of the diagonals in the right field—still opposite the Var.—shows much similarity to the A′. The later (B′) series, however, marks a shortening of the vertical measurements, while M 0 seems more yielding than formerly to some extraneous influence, apparently that of adjustment.

Series C and C′.—In both instances the left field is greater than the right (in agreement with A and A′); the upper field is larger than the lower. The latter feature has in it presumably the influence of the Var. at M 90′.

Series D and D′.—Again there is elongation in the field (this time the lower) opposite the Var., with a tendency to correction with practice. The high variation between the series shown here renders uncertain any attempted distinction between the "primary" and "secondary" forces that would control the relative values of the upper and lower fields. There is in this case a nice balance between the right and left sections of the field, with the slightest difference in favor of the left.

Series E.—In the final average, *the enlargement of the left field, though small and especially so at M 180, persists. The upper vertical has become longer than the lower; the lower diagonal extents remain greater than those of the upper field. In both fields the V-H illusion continues prominent, giving to the entire graph the general prolate form.*

There is a resemblance here to the type field of Jo., but with less consistency. The work of this subject showed a rather high average variation. She was cautious and hesitant in making her judgments—a method rarely conducive to consistent results.

Subject Py.

Series A and A′.—The graphs for this subject show a nearer approach to a circular field type than is seen in any of the preceding. The variations, in this series, between the different meridians are scarcely greater than the average variation for any single meridian alone. With practice there is a diminishing of all measurements, more on some lines than on others, and leaving a doubtful advantage over opposites in favor of the upper and left sections of the field.

Series B and B′.—The reversal of the Var. position gives a closer balance between the right and left halves and a pronounced overestimation of the lower with respect to the upper field, though the V-H illusion persists in both fields. The practice effects are ambiguous, and well within the average variation.

Series C and C′.—The first of these series shows an underestimation of the right horizontal line; the practice series shows both horizontals reduced, thereby bringing out distinctly the V-H illusion in the four relations. The upper and lower vertical lines are close to equality. All diagonals are slightly overestimated, with the exception of M45, which is underestimated.

Series D and D′.—Again with the earlier series the right horizontal is underestimated and in the practice series both right and left horizontals are reduced in their estimated lengths. The measurements in the lower field are slightly greater than in the upper. Practice shows a decrease of all the measurements and, excepting on M 0 and M 180, a nearer approach to accuracy, or equality.

Series E.—The average graph somewhat resembles that of Ba., in that it is *mildly prolate,* with *very "square" corners* which are more prominent in the lower field than in the upper, while the *upper vertical meridian is a very little shorter than the lower.* However, the small extension of the graph at M 180 preserves the resemblance to the earlier A and A′ series; but the figure suggests the possibility that the successful elimination of *all* disturbing factors might reduce the outline to something near a circular form.

Subject Ki.

Series A and A′.—Here is shown an enlargement of the left and upper fields over their opposites, with a flattening at M 45′. That most of the extension on the left was due at first to the adjustment factor is apparent by the correction for this in the later, or practice, series. The field is greatest in its vertical dimension, and this is elongated most in the upper portion.

Series B and B′.—Again there is the vertical length, but a tendency (not diminished by the given practice) to push the longer measurements to the field opposite the Var.

Series C and C′.—The vertical length continues. With respect to the Var. there is an underestimation of all lines, with the exception of M 90; the V-H illusion thus continues especially prominent in the upper field, though it exists also in the lower.

Series D and D′.—True to all preceding graphs, except the earlier B, the upper vertical line remains first in the order of size; all other meridians are underestimated. The opposition of the adjustment factor is either corrected for, or it is insufficient to overcome the difference in the upper and lower parts. Practice tends toward accuracy of estimation in the vertical-horizontal relation, or a reduction of the illusion, in the upper field.

Series E.—The most harmonious figure of the series, the one approaching most nearly the perfect oval, is that of the "primary graph" of this subject. *The long diameter is the vertical, whose greatest length, however, extends into the upper field. The entire upper field is markedly, and the left slightly, greater than the corresponding opposites.* There is a small underestimation at M 45′ (in opposition to Hu.'s shortening the figure at M 135′). The differences in the right and left fields are within the average variation.

Subject Ca.

For this observer the experiments of this section represent his very first work, and they were not repeated in full. There is a beautiful yielding to the influence of the adjustment factor, likewise a clear pointing to a definite *primary* given.

Series A.—All other lines are estimated longer than the Var. The greatest field length is vertical, with the greater enlargement in the upper extent. M 45′ is the one exception to the enlargement of the upper and left meridians over their corresponding opposites.

Series B.—Again the Var., though opposite from its former position, becomes the shortest meridian. The vertical elongation is slightly less pronounced, indicating that in this case either the adjustment factor is slightly guarded against or else that the left horizontal is actually *seen* a bit longer than the right. The former is probable.

Series C.—The vertical lengthening is clearer in this case—two factors may be supposed to work together. The upper field

is enlarged, and the horizontal lines (and to a slight degree the lower diagonals) are underestimated. The underestimation is greater on the left side.

Series D.—Making M 90 the Var. results in an underestimation of all lines that have heretofore measured less than this line, with the exception of M 45′, which was formerly given large measurements and is here supplemented by the secondary influence of adjustment. Other lines in the lower field are pushed out with respect to the upper more than in the former series. The right field is everywhere greater than the corresponding left parts.

Series E.—This graph presents the *oval form and in the upright position. With one small exception, covered by the average variation, the upper field is consistently larger than the lower, the right greater than the left.* The left horizontal is underestimated by a small amount, which, again, the average variation in a more extended series might cover.

Summary

(I) *Varying Features.*—(1) *Practice Effects.*—For the first four subjects of the group—those having a long series of intervening tests between the A and A′—there is a marked tendency to increase the overestimations of all lines with respect to the Var. (at M 0), with the exception only of the case of Hu., where the effects were directly the opposite. For the remaining subjects, for whom the series followed in succession—A, B, C, D, A′, B′, etc.—the practice effects are less consistent, but apparently the predominant tendency is to decrease the relative overestimations of other lines with respect to the Var.

(2) *Effects of Adjustment.*—The usual effect of meridional changes in the position of the Var. is seen (graphs B, C, and D) to be a disproportioned enlargement of the field opposite to the line that varies.

(II) *Permanent Features.*—*Normal Field Types.*—In the data examined (series E, right column of table and chart) there may be pointed out three pronouncedly different types of fields under which the individual forms are conveniently grouped. They are—

(1) *The Upright Oval.*—This form, with the lower field generally larger than the upper, and the left field slightly greater than the right, is evidenced by the observers Jo., Ba., and Py.;

with the right slightly superior to the left and the upper greater than the lower, by subject Ca.

(2) *The Circular Form.*—This might be included as a subdivision under the preceding head, since the vertical still is generally the greatest diameter of the field. Yet because of diminished differences in the diametrical aspects of the figures this group is segregated. Given, then, a figure approximating a circle, but with the pole of vision several degrees "eastward" and a little to the "south" of the center, and we have the type of Pe.'s "normal" field; with the pole even farther to the "east" and farther to the "south," we have Ta.'s type. With the "corners" further rounded, but a more pointed "tip" at the vertical extremes, the pole of vision slightly to the "south" and very slightly to the "east," this group may include also the type of Ki.

(3) *The Oblate Oval.*—The third type of field manifested in the E series, though it is an oval, has its greatest diameter in the horizontal direction. This is represented by the work of a single subject, Hu., in whose case the secondary influence of practice had its most unusual effects. In the early naive work of this observer (series A) only the lower field shows this oblate flattening.

Common to groups 1 and 2, and possibly to the upper field in type 3, is the superior length of the vertical diameter with respect to the horizontal.

A regrouping of the types, not on the basis of general outline, but in accordance with the estimations of the right *vs.* the left and the upper *vs.* the lower fields, would result, with few discrepancies, as follows:

First. The left field greater than the right, the lower greater than the upper: Jo., Ba., and Py.

Second. The left field greater than the right, the upper greater than the lower: Pe., Ta., and Ki.

Third. The right field larger than the left, the upper field greater than the lower: Hu., Ca.

No case was found showing the other possible combination, namely, the right field larger than the left and the lower greater than the upper. For six subjects the left field was greater than the right; two, the opposite. For five subjects the upper field was greater than the lower; for three, the opposite was true.

The common characteristic is, finally, the evident serial place in all field types of the vertical-horizontal illusion among the many meridional disparities.

Comparisons with Data fom Earlier Investigations.—Professor Münsterberg's early assertion that the left field is seen larger than the right would be abundantly corroborated if Pe., Ta., and Jo. had been the only observers in this experiment. Scarcely a contradiction would follow from the introduction of the data of Ba., Py., or even Ki. But the work of Ca. and Hu. speaks contrarily.

The results of Professor Stevens, showing the right field greater than the left, would find a delightful correlation in the final "normal" (?) graph of Hu., were it not for the genesis of this figure.

The inference from Kundt that the right and left fields should be nicely balanced in binocular vision is uncontradicted by at least five of the subjects, in whose work there is seen much wavering with practice and a final normal graph approaching a right and left equality.

The statement from Fischer that the lower field is overestimated with respect to the upper finds a counterpart in the reiterated testimony of Jo.'s estimations. Again, the work of Ba. and Py. lends some countenance to that assertion. The contrary views of Delboeuf are amply supported by the results of Ca., Hu., Pe., Ta., and Ki., which showed the upper field magnified with respect to the lower.

The general testimony of the authorities to the existence of a vertical-horizontal disparity, i. e., of the subjective overestimation of a vertical distance with respect to an equal horizontal extent, is borne out without exception if the concession is made (in accordance with succeeding evidence) that the later work of Hu. is dominated by a secondary rather than a primary condition of space perception, and that his earlier work is the more typical of his *normal* field.

The graph of Wundt (page 13) indicates that not only M 90 and M 45 are overestimated with respect to M 0, but all intervening meridians, between 90° and 45° and between 45° and 0°,

are likewise and proportionately overestimated. We are told that similar results occur in the four quarters of the field, and that only M 180 has subjective equality with M 0. This perfect symmetry has long been supplanted, according to that author himself, by later results. The field contains, nevertheless, a hint that leaves one the less surprised to find in the data of the present experiment the near-lying standards so often overestimated with respect to the horizontal Var. (See Graphs and Tables, angles α and α'.) And since this early work of Wundt was done under entirely different conditions, as to the features both of adjustment and of practice, it must be inferred that these secondary factors cannot alone be responsible for the very "square cornered" appearance produced in certain graphs by the overestimation of the diagonal lines. (Compare the "bulge" at M 15, Wundtian graph.)

The most pronounced and uncontrovertible general truth from this series of the present investigation is that under precisely the same objective conditions and with apparently the same bodily attitude, different subjects manifest subjective types of fields differing as widely in detail as do any of the contradictory factual results reported by earlier writers. The existence of *field types,* which differ among individuals and seem relatively fixed and characteristic, is, therefore, one of the principal facts of this section. The validity of this supposed fact will be subjected to further analysis in the discussion of those supplementary tests introduced for purposes of corroboration. A second truth equally evident is that the vertical-horizontal illusion takes a serial place, usually the highest, among the common meridional disparities of the visual field.

2. *Supplementary Tests*

These tests began in the early stages of the work and at first were introduced chiefly for the purpose of making sure that no unsuspected objective factor was distorting the results. Some, however, were given for their intrinsic and subsidiary interest. None was extended enough in scope to be classed with the theoretical tests described below (Part III.), hence the entire

group of minor tests will be reported together in this place. The topics included are the following: (1) Monocular Vision; (2) Inequality of Lighting; (3) Natural Elevation of the Head in the Primary Position; (4) Astigmatism; (5) Undeveloped Mentality; (6) Comparison of Equal Lines.

(1) *Monocular Vision.*—These tests were introduced during the early "normal" series in the first quarter's work. Their occasion was the fact that at that moment the four subjects then serving (Pe., Ta., Hu., and O.) were all overestimating the left field with respect to the right and it was desirable to know if this would occur with each eye separately.

The tests were made with the two horizontal lines only (Var. M 0, and St. M 180), and were not repeated. There was a total of thirty judgments for each subject. The averaged results are shown in the following tabulation, wherein the overestimations of the left line are given in millimeters:

	Ta. mm.	Hu. mm.	Pe. mm.	O. mm.
Binocular ...	44.8±3.	.4±0.9	21.4±5.	21.0 ±5.
Right Eye...	56.6±4.	7.0±3.0	33.0±6.	29.05±5.
Left Eye.....	39.5±3.	4.0±2.0	33.5±5.	29.5 ±2.

For three subjects there was an increase of the overestimation of the left horizontal in each of the monocular series; while in the case of Ta. the results for the binocular series occupy a middle place between the estimations by the right and left eye singly.

That there should be this increase for all subjects, even for Hu., whose original normal series gave underestimations for the left horizontal, seems indicative of a secondary factor producing the change. The increase of the illusion is greater with the right eye—the one nearest the variable line, as it happens—than with the left, markedly so for Ta. and Hu. and very slightly so for Pe. and O.

In this connection it is interesting to note that in Valentine's results with monocular tests[2] the vertical-horizontal illusion was sometimes greater with either eye of the subject than with both eyes together, and again that the amount in binocular vision sometimes occupied a medial place between that yielded by the

[2] British Journal of Psychology, Vol. V, p. 8 and p. 308. 1912.

two eyes separately. On these facts this author bases an argument for a distinctive retinal condition, varying in different eyes, as the causal factor in the vertical-horizontal disparity. The finality of this argument the present writer believes is rendered doubtful by the data above recorded. (See page 93.)

(2) *Inequality of Lighting.*—The possibility that the light by some undetected difference in intensity, reflection from the walls, position of the shades, etc., might have to do with the differences of estimation in the right and left sides of the field, was next considered.

The method of testing was that of turning out one of the lights and giving the usual series with one-half of the field thus slightly obscured. The results were negative. That is, the measurements fell well within the average variation for the normal series. The final outcome of the individual field types—the great variety there shown (Sec. 1)—is also an evidence that the method of lighting exerted no controlling influence in the course of the experimental events.

(3) *Natural Elevation of the Head in Primary Position.*—Later, in the second quarter's work, there appeared what promised an interesting correlation between the attitude of the subject's head in his primary position and the type of results he gave. Six subjects had then served. Five gave evidence of seeing the upper field as greater than the lower, and the same five held their heads well erect when the eyes were in the "primary position." This position of the eyes will be recalled as one of the norm conditions of the experiment. When it was fulfilled for a new subject (Jo.) his head was thrust well back between his shoulders, so that the adjustable chair had to be lowered several inches to make him at all comfortable with the apparatus. And this was the first subject the majority of whose results indicated an overestimation of the lower field with respect to the upper.

To test the matter of the correlations it was necessary to find other subjects the shape or carriage of whose heads was similar to these characteristics of Jo. These were found, in the summer quarter, in the subjects S. and Po. They also, like Jo., were under the necessity of thrusting the head far back in order to fulfill the visual conditions of the primary position.

The results were not such as to *establish* the correlation. Po., the tilt of whose head was least marked, did overestimate the lower field with respect to the upper. But S., whose head was thrown farther back than Jo.'s, gave the opposite results. Other subjects, also, in the regular experiments occasionally gave the larger measurements in the lower field, though without the backward tilt of the head. Apparently, then, there can be no direct correlation between the attitude in the primary position and the character of the illusions. Yet this point remains to be noted: In the case of Jo. and Po. the characteristic *carriage* of the head, particularly in the listening attitude in the lecture room, was well erect, while the forward bend of the head was more characteristic of the remainder of the group, including S. The inquiry arises, may it be possible that the habitual erectness of the head (a natural assumption of the primary position?) may develop a corresponding attention attitude resulting in a livelier consciousness, on the part of such subjects, of the details of the upper field (viewed by the lower retina) than is experienced by the other group of subjects? This is a problem belonging more properly to the topic of Attention. (See Part III, Sec. 5.) That no influence from the muscular strain incident to the position entered into the results is evidenced from the series of tests involving changes in that feature. (Part III, Series 1.)

(4) *Astigmatism.*—No regular experiments were made involving this aspect of the problem. However, in the earlier part of the work when the matter of accounting for individual peculiarities first arose, the well-worn question regarding astigmatism came up. Accordingly, two subjects with opposite types of "fields" (Hu. and Ta.) consented to have their eyes tested for this defect. These tests were made by competent opticians in the laboratory of the Northwestern University Medical School.[3] The results, both as to astigmatism and in the matter of muscle balance, tested at the same time, were practically negative in each case. The former was nowhere above .5 D.[4] The very slight

[3] Thanks are due to Dr. Stella Vincent for assistance in this matter.

[4] C. W. Valentine (British Journal of Psychology, Vol. V, p. 308) has established that astigmatism not above 1.5 D. is ineffective in changing the apparent length of lines.

difference in the findings for the two subjects seemed inadequate to account for the wide divergence in their "types of visual field." These results concur with the conclusions of those who have made a special study of astigmatism in relation to the vertical-horizontal illusion, namely, that such defect is insufficient to account for the phenomena in question. (See page 74.)

(5) *Undeveloped Mentality.*—As all the regular subjects of this experiment were of a high type of mentality, it was simply a matter of curiosity that led the investigator to accept an opportunity to test one of a markedly different class. Accordingly, when a fifteen year old, slightly subnormal, girl was brought into the laboratory for the Binet-Simon tests, the writer, who assisted in that work, found it easy to introduce as a part of the day's program a series of the vertical-horizontal tests. The child, naturally obliging and willing in all she did, entered into this as a new kind of game, and one in which she was determined not to allow herself to be beaten. The primary position was not found in her case; her chin was merely rested against the rod of the headrest in such a way as to hold the head steadily in what appeared to be its normal position. Only two meridians, the vertical and horizontal, were used, and thirty judgments were obtained.

The results were not singular. There was the same type of illusion as with the other subjects (percentage of overestimation of the vertical about 7%). The chief difference lay in a much larger average variation and a greater assurance on the part of the subject of being "exactly right" in each estimation.

The results in this series are in harmony with former findings in tests made upon children[5] and inferior races[6], namely, that all are found to be subject alike to this deception of the visual sense.

(6) *Comparison of Equal Lines.*—The experiments of this

[5] W. H. Winch: "The Vertical-horizontal Illusion in School Children", British Journal of Psychology, Vol. II, p. 220.

[6] W. H. Rivers: Report of Cambridge Anthropological Expedition to Torres Strait. 1901. "Observations on the Senses of the Todas", British Journal of Psychology, Vol. I, p. 321.

group more than any of the preceding have a bearing upon the validity of the normal group of Sec. 1. The work was in three series, two of which (A and B) were given very early in the course of the investigation and the third (C) much later. The object in series A was to rule out for a time the factor of objective movement, or the adjustment of the Var. In B the aim was to discard, in addition, another previously uncontrolled feature, namely, the changing angular distance between the St. and the Var. in the successive positions of the former. The third series, C, involved the presentation of the entire "field," or the eight meridians, simultaneously.

In the first instance, series A, there was the usual comparison in the normal order of the seven remaining meridians with the right horizontal. The difference was that in this case the horizontal did not vary in length, though the subject was unaware of this fact. He was instructed that in accordance with a temporary change of plan he was to hold a card before his eyes while the "adjustments" were made and that in giving his judgments he should state his estimations of the difference in length of the two lines in terms of a millimeter stick (200 mm. in length) which he held in his hand. Which of the lines was the "Var." in these supposed adjustments was not stated to the subject. Two series were taken, the judgments alternating in pairs, in one of which the subject said, for example, "The vertical is —— mm. longer (or shorter) than the horizontal," and in the other, "The horizontal is —— mm. shorter (or longer) than the vertical." As a matter of fact, and as stated above, the two lines were in every case of exact equality. No observer seemed to suspect the ruse, though one, Jo., greatly reduced the illusions by practice during this series.

A total of twenty judgments (or a double series) was given by each subject upon each of the seven different pairs of lines.

The second series of comparisons (series B) was similarly made, except that the lines were in opposite fields, or 180° apart. Thus the upper vertical was compared with the lower, the right upper diagonal (M 45) with the left lower (M 135′), and the left upper diagonal (M 135) with the right lower (M 45′).

These three pairs, together with the right and left horizontals, which were included also in the A series, afforded a direct comparison of the right and left, and the upper and lower fields, without either the intervention of the angular distance factor or the disturbance of adjustment. The five subjects of series A and B were Hu., Ta., and Pe., whose first normal work had preceded these tests, and Jo. and Be. who began with these series.

Series C, in which the eight radii were simultaneously compared, was given at the close of the work with three of the then "practiced" subjects (Jo., Pe., and Hu.) and at the beginning of the work with a new group of observers (Ca., Ki., Ba., and Py.) who served only in the final quarter of the experiment. It was deemed possible that long experience with the adjustable line at the right might in the case of the earlier subjects have induced a habit which, carried over, influenced the results in this work, even though the factor of adjustment was now eliminated. Accordingly, the eight-equal-line test was given to the new subjects at the beginning of their work, before habit formation had commenced. It was planned also to repeat the series at the conclusion of their work (in a C′ series) and thus to test the effects of habit in their case.—The final series was carried out in the case of but one subject, Ki., and the original series failed in the case of two (Ba. and Py.) who were unable under the given conditions to control the attention shift.

The procedure was as follows: A large cardboard was prepared on which was drawn, radiating from the center, on each of the eight meridians used in the experiments, a black bar of corresponding width and length with the standards used (7 x 140 mm.). The figure corresponds with the equal radii drawn in the graphs (or with Figure 3). A perforation at the center admitted the central fixation pin of the apparatus, and the corners of the cardboard were attached to the frame by thumb tacks. The figure was covered until the subject was seated and his head adjusted. Judgments were given as promptly as possible after fixation was attained. The subject was asked to state which was the longest and which the shortest of the eight lines. Thereafter he stated the order of the intervening lengths, to the best of his

ability, with *estimations* of the differences. *Measurements* of these apparent differences were then made by sliding bits of white paper (folded through slits cut at the sides of the drawn bars) to the points where the subjects pronounced all the lines equal to the one that *seemed* the shortest. Again, as the reader understands, these lines were objectively equal *before* these adjustments.—Great accuracy cannot be claimed for this entire series. It was not repeated, and was open to the danger of wavering attention, or wavering fixation.

Results.—In Table II the full data of this experiment is given, while in Chart II are presented four of the typical resulting graphs. These are: series A for Jo., B for Hu., and C for Pe. and Ki. In Chart V the central figure in the drawing for Ta. is also from this group of tests, series A.

The principal facts evidenced are these: (1) The series A for Ta., occurring very early in her work (series number 8 and 9), is with very small deviations a close copy of the type of meridional disparities shown in the graph of her normal series A (number 5) which shortly preceded it. (The difference in the size of the two figures is marked. This may be due in part to the omission of the adjustment factor in "equal line" series, but it is doubtless occasioned largely by the change in method of obtaining the estimations. This subject protested that she was unable to give reliable statements of *how much* the lines differed in extent. By the previous method she had only to say when they were apparently equal, when not. Besides, in this case, as she described it, she was "translating" space on the distant cardboard into terms of near-at-hand space—the millimeter stick—as one might do in making a drawing or in transcribing blackboard script into pen and ink dimensions. The conviction that her estimations were inaccurate added somewhat to her feeling of confusion. Her success, then, in so uniform a "translation" is the more remarkable; and her statement of the case doubtless accounts accurately for a large share of the decrease in size not only in her own graph but in those of others of the subjects as well.)

(2) The A graph for Jo. represents his first work (excepting

very preliminary and explanatory exercises). It clearly foreshadows his first norm series A and his final, primary, graph E; there is the same typical outline.

(3) In the figure given for Hu., based upon estimations of opposite lines, in every case where a lower line is compared with an upper line, the latter is overestimated, and in every case not conflicting with these the lines at the right are overestimated with respect to those at the left. This is in perfect harmony with all of this subject's work, and the graph is seen in close resemblance to that of his original normal series A, which shortly preceded this series.—The later work, C, apparently was dominated by the attention attitude of that period; but, on the whole, there is nothing to controvert the statements based upon the subject's normal series.

(4) In the C series the graph for Pe., based upon his 34th, or *last,* series of tests, reiterates the peculiarities of all his preceding work (compare with Charts I and IV); while that shown for Ki.—representing his *first* series—is in unique harmony with all his succeeding data. (See graphs A′ and E, Chart I.)

While the graphs shown in the charts are *selected* from the possible ones of this list, it must be evident from the table (Table II) that the remaining figures, though in some cases less exact in certain details of the correlation with the normal series, bear nothing contradictory to the facts of the preceding section.—In all this work, especially that showing high consistency, the average variation was exceedingly small, less than one millimeter, for example, in the case of Pe. Such harmony of results, therefore, from methods so diverse greatly strengthens the evidence that so far at least as these subjects are concerned there exist typical peculiarities that are innate in each individual's perception of visual form.

Summary for Sec. 2.—It may be said with definiteness that neither in the equal line series nor in any other of the supplementary experiments is there found aught to invalidate the conclusions as to the type forms of the visual fields of the subjects serving in this experiment. On the contrary, in the monocular

series, in the series involving unequal lighting of the field, and especially in the equal line series, these observers verify with remarkable unanimity the truth of their results as shown in their "norm" and "primary" graphs.

3. *Place of the Vertical-Horizontal Illusion in the Meridional Disparities*

From the preceding sections, 1 and 2, is taken the following summary as to the relative position and significance of the vertical-horizontal illusion in the various field types.

There are five possible aspects of the V-H illusion in this problem. The first and broadest, perhaps the most significant, is the general relation of the vertical and horizontal dimensions of the entire field. The others are the four radial comparisons, starting from the pole of vision, namely, the upper vertical with the right and left horizontal lines and the lower, or hanging, vertical with the same right and left horizontal radii.

On the basis of the general aspect of the whole field the group types have been described. Those fields in the more prevailing form of the upright oval impress one immediately with the prominence of the V-H illusion. Those approaching the round type, or the oblate form, tend to obscure or reverse this illusion. A closer inspection, however, discloses certain other facts. By taking the final or "primary" graphs, series E, Chart I, and the norm graphs for Ta., Chart V, for a basis of inspection it is found that in only one case (Hu.'s) is the horizontal dimension greater than the vertical, while even the graphs for Pe. and Ta. (the more nearly round, or "square," type) show that the vertical line passing through the pole of vision—the M 90 + M 90′—is the *longest diameter* of the field.

A total of five graphs—those of Pe., Ta., Jo., Ki., and Ca.—shows the longest diameters in this same position, namely, the vertical meridian passing through the *pole* of the field, and this notwithstanding the variety of eccentricities at the different "corners" of the figures. On the other hand, two subjects—Ba. and Py.—show that either of the diagonals passing through the pole, or fixation point, is greater than the vertical diameter cutting the same center. But these subjects agree with the five whose longest line is the vertical in showing the *shortest* diameter of the field in the horizontal direction. This feature of the seven graphs agrees with the striking shortening of the horizontal line in the Wundtian figure (page 13). It is possible that compara-

tive *underestimation* here is as effective as *overestimation* elsewhere in the production of the total vertical-horizontal disparity.

To return from the inspection of the diameters to the comparison of the radial relationships, there is not found so nearly a uniformity of type. It is here that the individualities and eccentricities play the chief part. For those subjects—Pe., Ta., and Ki.—showing usually the left and upper fields larger than the corresponding opposites, the illusion in the upper right field (M 90 *vs.* M. 0) is the greatest of the four radial V-H disparities. For Pe. and Ta. the M 90′ *vs.* M 0 follows next, and because of the immense widening of the left field the overestimation of either the upper or lower vertical with respect to the left horizontal is very small—occupying, in fact, practically the lowest place among the radial differences of the field as a whole. For Ki., in whose case no such widening at the left exists, the M 90 *vs.* M 180 stands second, the M 90′ *vs.* M 180 last, of the four radial V-H disparities; and these are at the head of all the radial differences of his field with the one exception that what is fourth here drops to the fifth place when the entire group of radii is considered.

When the right field is greater than the left, or the lower greater than the upper, there is a corresponding shift among the various relationships of the four cardinal radii; for instance, Jo. has his largest illusion (13%) between M 90′ and M 0, while that of M 90′ and M 180 is almost as great as that of M 90 *vs.* M 0.

In the case of those subjects showing long radial extensions in the diagonal directions, the radial V-H illusion (as noted in the graphs of Pe., Ta., Ba., and Py.) may drop in some quadrants to a very minor place among the numerous disparities of the field.

Finally, to sum up the matter, the vertical-horizontal illusion, prominent in the upright and transverse diameters of practically all normal fields, is again apparent in radial comparisons, but in the latter takes among the many disparities existing between the different radii a place determined by the peculiar location of the pole of vision in each subject's typical field. That the vertical-horizontal illusion, in a linear sense, is but a typical form of radial differences is indicated, first, by its appearance in serial order among them, where all have been produced by like or similar conditions; and, second, by the fact of its being subject

with them to conditions—such as adjustment and practice—that change the amount of the different illusions. It has been shown that for a majority of the subjects it is also the most *prominent* type of radial disparity. On the other hand, it must be further evident that each diagonal-horizontal discrepancy is in turn but a varying aspect of the one controlling discrepancy between the vertical and horizontal dimensions of the entire field.

The form of the entire field, then, since the vertical-horizontal illusion is not an isolated phenomenon, becomes the crucial matter for explanation. Any theory that would account for the vertical-horizontal illusion, or *any other* radial discrepancy, must, therefore, take into account this entire subjective figure of the upright oval which represents the objective circle. It is not sufficient that one authority should explain why in his case the left side of the field appears larger than the right, when he has not extended the application to include fully the vertical-horizontal relationships, or that another should account for the numerous over-estimations of the right field in his experiments on the basis of a physiological or anatomical condition that cannot in any known way apply to the more prominent differences between horizontal and vertical diameters of the field. But the question of the underlying cause must be left until these visual disparities have been viewed in a still further relationship, namely, the foveal-peripheral.

Summary of Part I

(1) For the given objective fields, of circular form, the subjective fields normally appear of markedly varying dimensions. Among these subjective fields, as observed in this study, there exist certain pronounced group types.

(2) Within these group types there may be well marked individual variations.

(3) The vertical-horizontal illusion holds a varying place with the other radial disparities in the different types, but in the main the totality of radial or meridional differences tends to produce a vertical elongation of the entire subjective field.

(4) As the vertical meridian through the pole of vision tends to be the *longest* diameter of the field, so also the horizontal meridian, with rare exception, is the shortest diameter.

(5) Supplementary tests—involving monocular vision, inequality of lighting, elevation of the head in the "primary position," astigmatism, undeveloped mentality, and the judgment of equal lines—have but served to verify, without hint of explanation, the results of the normal series.

(6) Practice and "adjustment," features common to all series, are disturbing influences measurably affecting all types of radial disparities.

(7) Since subject to a common origin and common influence with other radical disparities, i. e., between the right and left and the upper and lower fields, the vertical-horizontal illusion must have a common explanation with the entire group of such phenomena.

PART II. FOVEAL AND PERIPHERAL MAGNITUDES OF THE MERIDIONAL DISPARITIES

The outline, or boundary, of the normal field was determined, for each subject, in Part I. It is the purpose here, in Part II, to explore central and peripheral areas lying *within* the normal field. The broad question becomes: *Are the meridional disparities discovered with the normal standard characteristic for any length of line, or is there a varying "unit" of estimation in passing from the foveal to the marginal parts of the field?* The inquiry has an explanatory as well as an exploratory interest. All other conditions, i. e., central fixation, eye muscle strain, objective details, etc., remain, so far as controllable, the same as in the normal series. Only the retinal parts affected are altered with the change in the length of lines and with their peripheral and central placement. However, all questions of an explanatory bearing are to be deferred until there have been examined, in Part III, certain of the features assumed above as constant. The immediate purpose here is, then, to extend our list of *facts* concerning the visual field. The study connects with such others as have dealt with foveal and marginal differences of estimation, i. e., with direct and indirect vision.

Three authorities, Chodin,[1] Fischer,[2] and Münsterberg,[3] have

[1] Von Graefe's Archiv für Ophthalmologie, B. 23, S. 92. (1877).

[2] Von Graefe's Archiv für Ophthalmologie, B. 37, 1, S. 97-102; 3, S. 55. (1891).

[3] Beiträge zur Experimentellen Psychologie, H. 1, S. 125. (1889).

investigated the applicability of the Weber-Fechner law[4] to visual measurements, but with differing conclusions. Chodin finds that with lines in the V-H relationship, "the accuracy of estimation decreases gradually with the increase of distance, i. e., with the length of St., except that with large distances it increases again." This is to say that the illusion is larger with the longer extents up to a certain limit, beyond which the lengthening of the standards causes the illusion to diminish. Münsterberg, whose work showed much irregularity of result, held that the Weber-Fechner law does, nevertheless, prevail in foveal-marginal disparities—or those existing between direct and indirect vision. These he reduces to a matter of muscle strain, to the *intensities* of which—as to the intensities of light and other sensations—the given law applies. Fischer, again, holds that a modified form of the Weber-Fechner law prevails in meridional estimations; that is, he accounts for the V-H disparities on the basis of a supposition that the eye has different "Maasstäbe," or measuring units, for the different meridians of the field. Upon the supposition that these units prevail for any length of line, the following formula is given for the relative objective lengths that appear equal in the four principal meridians of the binocular field:

Lower	: Upper	: Left	: Right
100	103.22	114.49	115.44

This means, of course, that the lower vertical is overestimated with respect to the upper vertical, that the left horizontal line is overestimated—to a less degree—with respect to the right horizontal line, and that both the lower and upper verticals are greatly overestimated (approximately 11% to 15%) with respect to the right and left horizontal lines. This author also found that in halving one of the four radii the outer half was underestimated with respect to the inner.

Professor Steven's results[5] are contrary to the last mentioned item. That is, marginal parts were shown to be overestimated

[4] This law would imply here that with uniform stages in increasing the stimulus there would follow a uniform increase (i.e., an equivalent percentage) in the amount of the illusion.

[5] Psychological Review, Vol. XV, p. 69.

with respect to central areas. This would point, not to a Weber-Fechner uniformity, but rather to an increasing, or at least a varying, percentage from the focal to the marginal end of the given lines.

In the present study, connecting itself, as stated, with the "normal" problem of Part I, three questions will be considered: (1) Will the same individualities found in the normal type forms prevail with shortened standards, other conditions remaining as before? (2) Will such shortened standards medially and peripherally placed (i. e., with the central junction of the two lines broken by increasing stages) yield again the typical meridional illusions? (3) Finally, are all parts of a given pair of lines equally responsible for the disparity in their subjective estimations, or is the normal illusion produced more by one part than another of the given lines?[6] What, in other words, is the percent of the illusion in the successive segments studied? Is it uniform or varying?

This is an ambitious field of inquiry within itself, but unfortunately the work here had to be abridged because of the necessity for an abrupt closing of the experiments before their conclusion. However, such results as were obtained (nearly 10,000 separate judgments) are deemed worth recording.

The subjects serving were those of the summer quarter (1912), namely, Ba., Py., Ki., and Ca., whose work varied markedly in type from that of the remaining subjects who had served from two to four quarters in the experiment. There were two series, in accordance with the first two questions named above, and from these the data for the third topic also was obtained.

1. *Central and Medial Field Types*

Briefly stated, the problem of this section is to determine the effect of variation in length of standard, the point of junction of the two lines continuing as the center of fixation. The three

[6] Note: In this study the foveal parts were compared with foveal, and peripheral with peripheral, on the same meridians used in the preceding sections. There was no direct comparison between foveal parts and peripheral parts, as in the work of Professor Stevens.

standards employed were the following: St. 1 (the normal of the preceding series), 140 mm.; St. 2, 85 mm.; St. 3, 30 mm. The visual angle and retinal extent covered by the three were respectively as follows: 6° 12′ and 1.73 mm.; 3° 46′ and 1.95 mm.; 1° 20′ and .37 mm. A preliminary series had involved the use of standards of three different lengths (260, 210, and 160 mm.), but there the purpose was to find a convenient norm for length. This study did not involve the extreme periphery of the field, but was limited almost entirely to the region of clear direct vision. The retinal image of St. 1 extended little beyond the macula lutea in its horizontal dimension. (See page 83.) St. 2 outlined a field a large section of which was wholly within the macular area, while St. 3 described a circle which in retinal space covered only the fovea and its immediate boundaries.

The procedure, with the exception of the amount of work covered, was the same as in former series. Three subjects finished one complete series (A), with all the meridians, with each standard. Thereafter, because of limited time, they were restricted to four meridians, or radii, namely, the upper and lower vertical and the right and left horizontal lines. For one subject (Ca.) all tests with Sts. 2 and 3 were limited to two meridians, the upper vertical and right horizontal, on which the positions of the St. and Var. alternated in successive series.

Results.—(See Chart III and Table III, Part 1.) The absolute and relative errors[7] for series A and E are given in the table; the intervening series, B, C, and D, are omitted from the tables, as they offer nothing new. The graphs for this section (Chart III) are superposed, the smaller lying within the larger. The lengths of the shorter standards are indicated by heavy dots. The over- and underestimations are represented, as formerly, on a scale five times too large in proportion to the length of the standards. The entire field, or largest graph, may be thought of as the "norm" field; the middle sized graph, that of St. 2, as

[7] An "absolute" error is, as formerly, the amount in millimeters the Var. departed from equality with the St. when the lines appeared equal subjectively; the "relative" error is the *percent* of the illusion, with the length of the standard as the base.

the "medial" field; and the small central section, built around St. 3, as the "central" field. These are indicated on the graphs and in the table by the letters *N, M,* and *C.*

Series A.—Of the three graphs presented two (for subjects Ba. and Ki.) indicate a fair degree of harmony in the field outlines—central, medial, and norm. With further practice, or with the average of a longer series, the likeness of outline doubtless would have increased rather than diminished. Practice effects previously pointed out indicate this possibility. The third graph (that of Py.) shows in the norm field a beautiful smoothness of outline, but with the decrease of the standard lengths there begins a series of reversals of the V-H illusion which breaks the form of the graph. The tabular data for this subject shows St. 3 underestimated everywhere except upon two meridians of the lower field. St. 2 is underestimated upon two meridians, notably upon M 90. The data for Ca., whose graph is not given, shows in his one series (see table) the prevailing tendency toward smaller absolute disparities with the decreasing standard lengths, but the table of relative values shows, nevertheless, the errors in the smaller fields are disproportionately large. This is doubtless due to this subject's habit of overcorrection for the influence of adjustment.

Series E.—A superficial glance at the graph of series E (the average of A, B, C, and D, for the four cardinal meridians only) will indicate that some force stronger than the influence of adjustment is controlling the type forms, for subjects are seen to repeat in significant details characteristics of their A series.

But individuality of type presents here a new feature. Not only do the types differ from individual to individual, but the same subject (e. g., Py.) may show markedly different outlines, or meridional relationships, in the marginal, medial, and central fields.

2. *Peripheral Comparisons*

Reversing the procedure of Sec. 1, that is, shortening (or separating) the lines by increasing stages at the central ends, there is obtained a supplementary set of data, of similar import to the preceding, but in which peripheral rather than central areas are examined.

The device employed to attain this end was that of placing circular discs, of pale yellow paper, over the center of the field, thus cutting off the central ends of the lines. (See Fig. 2, C.) The slight color contrast with the surrounding field was intended to emphasize the circular form, or the fact of the equal distance of the given lines from the fixation point. The discs used (see Fig. 6) were of the following radial dimensions: D. 1, 7.5 mm. (barely breaking the connection of the St. and Var. lines); D. 2, 30 mm.; and D.3, 85 mm. Used successively with St. 1 (140 mm.), there are obtained three figures in addition to the normal field. (See Chart III, Part 2.)

Discs 1 and 2 were also used with St. 2 (85 mm.), and so within the "medial" field there were *three* figures for comparison, including the normal of this series. With St. 3 (30 mm.), two figures were obtained, as the first, or smallest, disc could again be used, thus marking off the peripheral boundary of the "central" field also.

Results.—Table III, Part 2, gives in percent the amount of the over- or underestimation of the upper and lower vertical and the left horizontal lines, M o being the basis of comparison. This is an E′ series; i .e., the average of series A, B, C, and D is taken *after* a previous average has been made of all possible values in the case of each segment, obtained by the intercomparison of data. (See explanation, Sec. 3). The graphs of Chart III, Part 2, are illustrative of the type figures produced by this series, and are based upon the absolute overestimations of the A series, subject Ba.

Reading the tabulation from left to right the following facts become apparent:

(1) *Upper Field, or M 90.*—There is a comparatively uniform tendency to increase the error of overestimation as the distance between the lines becomes greater, i. e., with the use of the larger discs. The principal exceptions are in the outer rims, where the lines are very short; e. g., St. 1-D.3 for Ba. and Ki.; in the outer part of the medial and central fields (St. 2-D.2 and St. 3-D.1) for Py.; and in Ca.'s work, particularly with the shorter standards. The reversal of the illusion occurs once for Py.,

twice for Ki., with St. 3. For the three subjects whose data was most complete there are but five exceptions (out of twenty-seven cases) to the general tendency to increase the overestimations as the central space between the lines becomes greater—or as the lines themselves are more and more reduced to marginal positions.

(2) *Lower Field—M 90′.*—Here there is less of uniformity, but the errors either of over- or underestimation are in a very large percent of the cases decidedly smaller than corresponding ones in the upper field. (This *may* mean a greater ease of judgment in comparing these lines in the lower vertical extent with corresponding parts of the right horizontal than is found in similar comparisons for the upper vertical line; or it *may* mean that eye movement—shift of attention—toward the lower field is more difficult to check.—This, however, is but a word in advance of the final effort at interpretation.)

(3) *Left vs. Right Horizontal.*—The differences between the right and left horizontal lines are yet smaller—with but rare exceptions, usually with the very short lines—than any of the errors previously pointed out. It was found in the normal series for these three subjects that with practice the right and left sides of the field approached a nicer balance. That the same would have followed here with practice is at least suggested by the character of the data. That the general tendency to increase the overestimation or decrease the underestimation with each remove from the center of the field persists here is also to be noted. There is but one possible exception to this last point, i. e., St. 2-D.3, for Ki.—a case easily covered by the average variation.

This section is chiefly significant as a supplement to Sec. 1. If in this series the percent of the illusion is found to increase as the stimulus is shortened at the center, or what is the same thing, is thrust toward the margin, while in Sec. 1 the percent was seen to decrease as the marginal ends were removed, and the lines were thus rendered more and more of a central character—then there is the double evidence that more of the total meridional disparity in a given case must be credited to the marginal than to the foveal regions of the normal field. The closer investigation of this point falls to the next section.

3. *Percentage of the Illusions in Foveal, Medial and Peripheral Segments*

The third inquiry of Part II is based upon the combined data of the preceding sections, by which it becomes possible to examine the zonal segments into which the field is now divided. Figure 6 makes clear what these zonal areas are.

The following are the questions: (a) Is the percent of the given meridional disparities uniform or variant in the successive zones; and, finally, (b) What part does each segment contribute to the total illusion of the normal standard, i. e., to those disparities of the "normal field" recorded in Table I?

Now since the normal standard is 140 mm. in length it might seem desirable to have had the four segments here of equal value, that is, 35 mm. in extent. But it was found in selecting the shorter standards of Sec. 1 that a difference of less than 55 mm. in the stimulus gave results differing from the normal less than the variations in the successive normal series. Hence, 85 mm. and 30 mm. were chosen for the shorter standard lengths, and discs 3 and 2 were made to correspond respectively with these. Thus the two outer borders become 55 mm. each, while the remaining two are determined by the radius of the smallest disc (7.5 mm.) and the difference between that and the length of St. 3, which difference is 22.5 mm. The four segments, then, counting from the center outward, are as follows: S. 1, 7.5 mm.; S. 2, 22.5 mm.; S. 3, 55 mm.; S. 4, 55 mm. See figure 6.

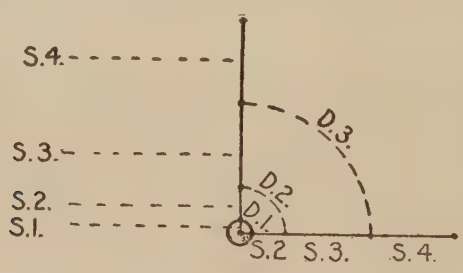


Fig. 6.

Now the value of S. 1 is nowhere directly determined, since a standard of so short a length was impracticable. It is obtained,

therefore, by the indirect method of comparison. By subtracting the value of the illusion of St. 3 (30 mm.) when Disc 1 is used from that of the same standard when no disc was used an approximation of the illusion in S. 1 is obtained. In the same way St. 2 and St. 1, by a comparison of their values with and without the small disc, afford each an additional estimate of S. 1. The three values of this segment are then averaged for the final approximate value of the tables. The value of S. 2 is obtained directly by the use of the 7.5 mm. disc (D. 1) with the 30 mm. St. (St. 3); of S. 3 by the 30 mm. disc (D. 2) with the 85 mm. St. (St. 2); and of S. 4 by the 85 mm. disc (D. 3) with the normal or 140 mm. St. (St. 1). In all of the A series, Table III, Parts 2 and 3, the values are thus obtained for segments 2, 3, and 4, and that for S. 1 by the first method named above, i. e., by the values of St. 3. For the A′ series all possible values for *each* segment are averaged; for it is quite as feasible to obtain by the indirect method of comparison additional values for the remaining segments as it is for S. 1.

The values for each segment in series B, C, and D, were obtained as in series A. Likewise these were subjected to intercomparisons, as for the A′, thus affording the B′, C′, and D′ series. By averaging A, B, C, and D, the data for the usual E series was obtained; and by averaging the A′, B′, C′, and D′, there was evolved the final series E′. In the above calculations the absolute values of the errors (i. e., in mm.) were used. The final proceeding in each series was to obtain the *relative* values, by reducing the data to the percent form—which is given in the tables. The method, of course, was that of dividing the amount of the illusion in each instance by the length of the standard concerned. This gives the data for Part 3, *a*, of the table. By dividing these same absolute values by 140 mm. there is found the relative amount (or percent) contributed by each segment to the total illusion of the normal standard. This is shown in Part 3, *b*, of the table.

Results.—(a) *Segmental Disparities.*—The indications of sections 1 and 2 as to the relative amounts of the V-H illusion in the different parts of the field are borne out in the combined data. Following are the more detailed facts.

Series A and A′. M 90.—The table (Part 3, a) shows that for three subjects the illusion of the upper vertical tends to diminish in percentage or be reversed (i. e., become negative) in an increasing percent, in passing from the margin inward—reading the tabulation from right to left. Reading from left to right it is clear that the positive illusion increases with each outward remove, i. e., from the foveal area to the medial and marginal segments. Ca.'s data are directly the opposite to this in series A, but conform in series A′.

M 90′.—In the lower field the regularity is less perfect. The negative illusions extend for some subjects further from the center, or appear irregularly. But it is still evident that the largest illusions occur in the more marginal segments.

M 180.—In the values of M 180 (compared again with M 0) the positive illusions, and usually the larger ones, fall once more in the outer segment.

Series E′.—When the factor of adjustment has been eliminated (and that after averaging the data in each series) it is still evident that for some subjects the illusion of the upper vertical is enlarged in the outer segments, i. e., S. 3 and S. 4, though three subjects show a higher percentage in S. 3 than in S. 4. This may be due to the fact that fewer values of S. 4 were obtainable for the averaging than in the case of S. 3. But it is necessary also to recognize that the direct value of S. 4 (St. 1—D. 3) was frequently negative.

(b) *Relative Contribution of the Segments to the Total Illusion of the Normal Standard.*—Peculiarly interesting facts arise from reducing the illusions of the separate segments to a percent of the normal standard. In this way it is to be determined whether or not the sum of the illusions in the parts will approximate the total normal illusion, or that observed when St. 1 is used alone.

Part 3, b, of the table gives both in millimeters and in percent (the latter on the basis of St. 1) the illusion of the norm or St. 1, the illusion of each of the segments separately, and finally the *sum* of the illusions in the separate segments.

The following are the facts indicated: (1) In the E′ series (shown in M 90 for all subjects) the difference between the sum

of the parts and the illusion of the whole is in every case in the neighborhood of 1 or 2 mm. and 1 or 2 percent—or what would be a small average variation in a normal series. As an example, in the data for subject Py. the sum of the illusions of the parts equals 6.02 mm. or 4.3%; the illusion of St. 1 is 5.06 mm. or 3.61%; the difference is .92 mm. or .69%.

The additional data given for Ba. in the table, indicates, in series E′, similar facts in the lower field, and even in the left horizontal, though there the dfference is greater, while in series A′ and A the correspondence (M 90) is extremely close. The difference in the latter series is less than one-tenth of one percent. Corresponding data for the other subjects, not printed in the tables, indicates a similar harmony.

In the majority of cases it may be noted that it is the sum of the illusions in the parts, rather than the total illusion of St. 1, that is slightly in excess over the other. *Possibly* this may indicate for these subjects a slightly greater difficulty in judging small lines.

It is now possible to inquire intelligently as to the contribution of each successive segment to the illusion of the whole line. Reading the data from left to right (S. 1 to S. 4) it is seen that the V-H illusion, sometimes negative in S. 1 or S. 2, generally increases in positive amount at successive removes toward the periphery. There are two exceptions—the slight one in the work of Ki. and the more marked in that of Ba.—wherein the illusion is less in S. 4 than in S. 3. This now occurs for Ba. only in the E′ series; the preceding series are freed from the exception, which was more common in section *a* of the table. In the main, then, the statement is fairly accurate that, as our field is divided, it is the outermost segments that contribute most largely to the meridional disparities of the entire field, while a questionable negative factor is discoverable in the central parts.

Comparison with the Data of Earlier Writers.—The phenomena of Part II of this experiment, including the "exceptions," are more in harmony with the finding of Chodin[8] than with those

[8] Whereas Chodin found the amount of the V-H illusion to increase with increase of standard length, up to a certain limit, then diminish again, this

of Fischer and Münsterberg. If there exists a "unit of estimation," varying from meridian to meridian, as Fischer claims, then it is apparent that it also varies from fovea to periphery along the same meridian. This would account for, or at least restate, the results of Prof. Stevens. The further supposition, that the rate of variation from the fovea peripheral-wards increases more rapidly upon some radii than upon others, unites the phenomena of this experiment with those shown in Prof. Stevens' work, while the individual variations above noted would rest upon a supposed irregularity in the variations of the "unit" in the different sectional parts of the radii. Certainly the phenomena are related with sufficient closeness to indicate that whatever is assumed as an explanation of foveal and peripheral differences of magnitude should be sufficiently broad to account also for fundamental facts of the vertical-horizontal illusion and kindred disparities.

Summary of Part II

(1) In the smaller, "central" and "medial," field outlines, described within the "normal" field, there exist again the V-H illusion and certain individualities of field types.

(2) In the marginal and medial *zones* of the normal field the typical disparities in meridional estimations reappear. That is, in lines shortened, or separated, at their central parts the illusions persist.

(3) The percent of the V-H illusion—sometimes negative in the foveal area—tends to increase in passing from the central to the peripheral parts of the field, at least to a certain limit, beyond which it *may* decrease again. That is, the "unit of estimation" was found to vary in successive parts of the different radii examined.

(4) The total of the illusions of the separate segments approximates closely the amount of the illusion of the norm standard taken as a whole. To this total illusion the marginal parts apparently are the largest contributors, while the central extents may tend to negative or reduce the total effect.

(5) From these facts it seems probable that the vertical-horizontal illusion connects itself with a series not only of meridional

experiment demonstrates that other disparities in estimation of meridional lines (*e.g.*, M 180 *vs.* M O) may be subject to a very similar variation. Doubtless differences of attention attitude are involved.

but also of foveal and peripheral disparities in subjective estimations of magnitude.

PART III. DETERMINING CONDITIONS: CONTROL TESTS

Certain supplementary tests earlier in the work examined minor conditions which were thought of possible influence in the outcome. These were not found effective. (See Part I, Sec. 2.) It is purposed here to examine in detail, and in their theoretical bearings, the following factors: (1) Ocular Position; (2) Bodily Position; (3) Objective Contour; (4) Practice Effects; and (5) Attention Attitude.

1. *The Effects of Ocular Position*[1]

The recognized inverse correlation of the relative strength of the ocular muscles with the directions of over- and underestimations in the visual field has rendered the Wundtian theory a popular one.[2] But since other physical features (e. g., contrast with the shape of the objective field) correlate quite as well, theoretically, with the facts of vision, it is possibly unwise to accept such a chance correlation as conclusive evidence of a cause and effect relationship. The apparent inaccessibility of the muscles themselves to experimental attack long served to keep the problem out of the laboratories. A study was made, however, some years since by Rivers and Hicks.[3] Their device was that of parallel series of momentary and prolonged exposures. The former, less than 1/50 second, were so brief, supposedly, as to exclude any actual eye movements, at least such as would aid in the estimations. Though they admit that Wundt's auxiliary doctrine of the *tendency* to movement as a possible basis of judgment has not been answered, their data is so clearly negative as to the value of the actually performed eye movements, that these authors and their followers[4] conclude the whole theory is groundless. The present experiment deals with the problem from an opposite line of approach. Instead of attempting to render mus-

[1] This series was at the especial suggestion of Professor Carr, and was the starting point of this investigation.

[2] Wundt: Outlines of Psychology, pg. 135.

[3] British Journal of Psychology, Vol. II, p. 234.

[4] Valentine: British Journal of Psychology, Vol. V, p. 8.

cular effort impossible, the purpose is to increase the strain, to induce effort. The thought is that whatever augments the *cause* of the illusion ought to increase the *amount* of the illusion, and the reverse also should be true. If in a position of intense strain of the superior or inferior recti muscles the vertical-horizontal illusion is found to increase, while with induced strain in the interior and exterior recti there follows a reduction of the illusion, here would be a correlation well worth recording in substantiation of the theory. If such results do not follow, one may at least look elsewhere for effective agents.

The specific procedure was as follows: A practice series of the normal order had been given until the subjects (Jo., Hu., Ta., Pe., and Be.) were all fairly well adapted to the experiment, that is, the variations between the "in" and "out" series, for example, were reduced appreciably. Other conditions remaining normal, there were introduced four successive changes in ocular position, effected by changes in the angular relation of the mouth bit rest to the objective field. Changes of 15° were at first tried, but proved so little disturbing in any way that 30° alterations were adopted. The four positions were as follows: (1) The head tilted backward, eyes looking downward across the lower face to the usual fixation point; (2) the head bent forward, eyes looking out across the brows; (3) head turned to the right, eyes looking left; and (4) head turned to the left, eyes looking right. Rest and normal series intervened between these successive changes.

Not only strain of the ocular muscles entered into this experiment, but the disturbance of the bodily attitude as well. The new positions of the eyes involved, further, a change of contour —or a modification of the natural oval of the visual field (in its entirety, rather than in its restricted sense of this paper). To illustrate, when the eyes were turned far to the left, the oval was shortened upon the right; turned to the right, there followed the reverse shortening. The adjustments up and down narrowed the oval. In addition, the features of the face—brow, nose, cheeks, etc.—obtruded unnaturally into the field with the different tests.

Three things are thus involved in this series: (1) the eye strain and eye movement theory; (2) the secondary factor of bodily discomfort and disturbance, together with intensified attention strain; (3) the Külpe contour theory. The greatest significance attaches to the first of these.

Results.—Unquestionably all subjects were disturbed, rendered uncomfortable, by the strain of bodily as well as of eye position, and by the consequent feeling of effort in attention. Table IV is a full record of the numerical results. The following are the principal facts: (1) The general form of the "fields" remains, with slight exception, noted below, as in the normal series. (2) The average variation, both between series and within the single series, is much increased. Such irregularities as Pe.'s occasional larger estimation in the lower field than in the upper, occurred also in a small precent of his normal series. (3) A general increase in the amount of the disparities is noted for all subjects, excepting Hu. In the case of the latter the reverse is true. Not only do the illusions diminish but they tend to be reversed in character, i. e., to become negative. (4) The features named under "3" persist and become more marked in the succeeding "normal" series. They are shown in a later section (Sec. 4) to be a part with the typical *practice effects* for each subject concerned.

The conclusion is evident, namely, that there follows from this test no type of result that is constant to or dependent upon eye position and muscle strain. It is further evident that the involved change in contour of the visual field is alike ineffectual in modifying the type of illusions shown. This, however, will be deferred to another section for discussion. These findings coincide with the negative results of Rivers's tests of muscle strain effect by its elimination. Whatever correlations may exist, then, between muscular asymmetries and the peculiar meridional disparities of spacial judgments seem no nearer than before to a substantial proof of a cause and effect relationship. Indeed if the elimination of the muscular effort and also its increase to the point of extreme intensity *both* fail to affect the amount of the illusion in the way demanded by the theory, there seems

a fairly positive proof that no such causal or automatic relation exists between the muscular movements and the visual spacial apprehensions.

2. *The Effect of Bodily Position*[5]

This series of tests, following shortly after that of the preceding section, involved a complete change of the subject's relationship with the whole objective world exclusive of the particular *visual field* with which the test is concerned. That changed with him. A couch and a pillow were added to the equipment and the principal apparatus lowered to the level of the subject's eyes; fixation was required as before with the head in as comfortable and natural a position as possible but without attempt to use the mouth bit rest. Four positions of the body were involved: the normal, the reclining to the right, reclining to the left, and the inverted head. In each of the attitudes the subjects found the variable line in the right field of vision—its accustomed place up to this stage of their work; "up" was in the direction of the subject's head, "down" in the direction of his feet. It follows, then, that with the reclining to the left the variable is upon the upper vertical with respect to the earth, the reclining to the right gives the variable the position of the lower vertical with relation to the earth, and in the inverted head position the variable is upon what is normally the left horizontal line. In all these changes, however, the variable is still the "M o" and the other meridians are designated accordingly, i. e., with respect to the subject rather than to the external world. There is, then, no change involved in the bodily or ocular relation of the subject

[5] The original suggestion for this section comes from Professor Angell. Mr. A. F. Buck made a brief investigation of the same problem in this laboratory some years ago. His subjects were placed in two positions, sitting and recumbent. Cords were used for the adjustments; standard lengths 20 cm.; distances from the eye, 60 cm. and 120 cm. Retinal arcs thus involved were wider, marginally, than in the present experiment. Since he does not find the illusion translated with bodily changes in position, and since his tests with eye movement give nearly identical results with those without eye movement, Mr. Buck concludes that "it appears improbable that the eye muscles at present play a dominant part in producing the illusion." Chicago Studies, Vol. I, No. 2, p. 7.

to the field as presented by the apparatus. With the same fixation at the center, and normal straightforward direction of the eyes, the retinal field affected is in all points practically the same as in all preceding normal series. The balance of the ocular muscles is the same, except for whatever change gravity or the new bodily position may introduce in the balance. Indeed, save for the inverted head test, the strain upon the eyes and the entire body was the very opposite from that existing in the preceding series. There the attitude was tense and very taxing; here in the reclining position everything was conducive to relaxation, even to somnolence. For these busy students the recumbent attitude was associated only with sleep. This tendency to drowsiness was the chief *disturbance* of the attitude, and the only *effort* involved was at wakefulness and at adjustment to the changed situation.

The questions involved are: Will a state of relaxation show results different from those of the normal or tense state of muscle balance? Will the change of external conditions be effective upon the relative lengths of lines in upper, lower, right and left fields? Will these meridional disparities remain fixed with respect to the retina or with respect to the earth? (The latter would connect with the whole question of openness of sky and nearness of earth in the origin of the vertical-horizontal illusion.) Further, will *mental* attitude toward the changed relations be effective? Lipps has said that, for instance, in an equilateral triangle the mental conception of any one of the lines as the horizontal base results in its underestimation and the corresponding overestimation of the other two lines. He further asserts that gravity is one of the influences entering into the "expansion and contraction and erection" of lines, and hence into their apparent length. In this series the effect of gravity in the V-H relationship is reversed from the normal.

The subjects in this series were Jo., Pe., and Hu. The results in detail (see Table V and Chart IV) are as follow.

Results

Pe.—With each change of the position of the body the characteristic "norm" graph reappears, except that the lower vertical

is measured slightly larger than the upper vertical and with the inversion of the head the enlargement toward the left and upper left field is made more pronounced by slight underestimation in the 45° meridians. The measurements in the right field, in other words, are reduced with the inverted position of the head. This does not appear significant in view of the general shape of the graph.

Jo.—The most uniform results were produced by this subject. The first and second series gave graphs falling well within the average variation of the normal series, while the inverted position of the head gave what might be accepted as a beautiful reproduction of the "primary" graph (Chart I, E). One discrepancy occurs in the first graph of this series (left reclining position). There is a slight bulge on the left side of the figure, or that part corresponding to the lower field as to the earth. This hints of a carrying over of a "mental attitude," since in the normal field of this subject the lower part was overestimated. But if there *were* such a tendency it was insufficient to distort the entire field and there was a quick readjustment to it, since it nowhere reappears.

Hu.—In the case of this subject nothing occurs with these variations except the increasing amount of the underestimations with respect to the Var., and this has been noted several times in connection with other series. The graphs, here drawn on the basis of M 180, are in close conformity with those for the same subject in Chart I.

The marked feature of the above results is the recurring, with all the changes of bodily position, of the type graph characteristic of the earlier and normal work of each subject.

In the matter of bodily position, then, as of the ocular, it seems safe to assume, in view of the negative results, that unless some chance attention or judgmental factor entered occasionally from these sources, the factor of eye or bodily position was not a disturbance in the general course of the experimental work, and that the results of the experiments in general must be attributed to influences more persistent and fundamental.

3. *The Effects of Objective Contour*

To Oppel[6] and Külpe[7] is due the suggestion of the position of the eyes in the face and contrast with the resulting oblate form of the entire visual field as the possible occasion of the vertical-horizontal illusion. Valentine[8] put the matter to experimental proof. He shortened the oval of the field by monocular tests, and found—the illusion frequently *greater* than in his corresponding binocular series.

In the procedure of the present experiment the variations of contour were effected by cutting the desired figures in gray cardboard and placing these in turn over the normal background, which, it will be recalled, was a circle of gray surrounding a white field. The forms employed were four in number but, by changes in position, afforded six varieties of fields in addition to the normal. These were: the oval, placed (1) horizontally and (2) vertically; the semicircle, (3) upper and (4) lower fields; the semi-oval, (5) upper and (6) lower fields. The radii of the semicircle coincided with those of the regular circle of the normal field, as did also the longest radii of the oval figures. The shortest diameter of the latter figure was 380 mm., or the least distance practicable with the length of standards in use. To insure the subjects' consciousness of the change of outline, bits of colored paper—red, yellow, or combinations of yellow and red, blue and yellow, etc.—were attached to the points of the ovals farthest removed from the central fixation point, or else opposite the ends of the lines to be judged. The subjects serving were Hu., Ta., Jo., and Ca. The usual double series of tests was carried through, for three of the subjects, and typical series were given to the fourth (Ca.) The mouth bit head rest was again used and the "primary position" maintained.

Results.—No tabulation of the results of this series is given in this report. For any subject the normal series just preceding this group of tests may be taken as typical of the results here. The variations are similar in kind with those of the practice

[6] See references, p. 1.
[7] Outlines of Psychology, p. 366.
[8] British Journal of Psychology, Vol. V, p. 8.

series of the normal order. Subjects continue to increase the size of their measurements, but this feature is independent of the presence of the unusual in contour.[9]

Such findings accord with the negative results of Valentine. In so far as this experiment bears a small weight of evidence neither the horizontal arrangement of the eyes in the face nor the sky-earth relationship—nor the "aesthetic" effect of gravity —can be considered effective influences in determining the meridional disparities of the visual field.

There is left an admitted possibility, not touched here, that habits long established, resulting from such external causes, may not be amenable to momentary laboratory control. But the contour theory itself is equally without any positive evidence in its favor.

4. *The Effects of Practice*

This topic bears two aspects, namely, the general effects of continued practice (present from the beginning in each subject's work), and a special series here introduced for the purpose of a separate study of this feature.

General Practice Effects.—The cumulative effect of practice in succeeding series (many of which fell chronologically between the A and A′ norm series) is shown in the graphs of Chart I, and the matter is further supplemented by Chart V. (See also Table VI.)

Briefly, these effects are as follows: (1) With those subjects for whom the position of the variable line was altered in successive series the tendency is more to *reduce* than to increase the illusions with practice, (see graphs of Ba., Py., and Ki., Chart I), and for these subjects there appears finally (normal

[9] The changes in contour, it is true, were accepted by these subjects with a determination not to be diverted from the central object in the field. The paper "flags" especially were met with sniffs. All said, in effect, with Ta., "We are not kindergartners to be influenced in our judgments by a bit of bright paper; besides it is not so bright that far out in the margin." But the very comments assured the experimenter that the paper was noticed and hence was serving its purpose, namely, that of making the subjects conscious of the periphery while attending to the center of the field.

graph E, Chart I) an almost equal balance between the right and left horizontal lines, with respect to which all other meridians of the field incline to overestimations—and overestimations of such a type as to produce ultimately a fairly harmonious vertical lengthening of the entire field. (2) With those subjects, on the other hand, for whom the variation in the position of the adjustable line was one of the last series given, the tendency in the main was toward increasing overestimations of all other meridians with respect to M o—the Var. (See Jo. and Pe., Chart I; also Ta., Chart V.) The personal peculiarities of this latter group of subjects (pointed out in Part I) not only continued but increased in prominence in successive series. The only proof, then, of any valid primary difference between the individuals lay in the fact that these peculiar traits appeared in series wherein either practice or adjustment, or both, were non-effective. (See E graphs, Chart I; also "Equal line" graphs, Chart II; and the central outline for Ta. in Chart V.) (3) Subject Hu. is in a class to himself as to results, but is in the second group, above, as to method. (See Chart V.) For his first dozen series he continued to give results of a type with those of graph A (Charts I and V). Thereafter for some half dozen series he dropped into the habits of the remainder of his group (Jo., Pe., and Ta.) and increasingly overestimated everything with respect to the Var. (Chart V. graph A^2.) Thence on, he *under*estimated, and in an increasing percent, everything with respect to the Var. (Graph A′, Charts I and V.) Again, only the persistence in all these figures (A, A^2, and A′) of larger measurements in the upper field than in the lower and, usually, of greater estimations in the right than in the left halves (seen finally in "E" of Chart I), gives any grounds for supposing there has been in this subject's work any fundamentally and primarily fixed condition underlying what he perceives as forms.

Now since the changes incident to practice in the case of the two main groups of observers bear so close a relationship to the *method of adjustment,* it is logical to assume that the two distorting elements observed in the study of the "normal field" (Part I, Sec. 1) are but the initial and cumulative effects of *one*

disturbing factor, namely, objective movement in the adjustable or variable line,[10] and that Hu.'s deflections are but indicative of changing subjective attitudes toward this objective disturbance. —It should be said again that care was taken from the beginning to guard against the effects of adjustment. Subjects gave their judgments only when the Var. was stationary, and averted the eyes while the changes dictated were in progress. Nevertheless, their knowledge of *where* the changes were taking place invited to eye shift in the direction of the Var., in order to verify the dictated alteration.

It has been well recognized in previous investigations that the method of "production" or "mean error" is subject to variation in results with changing direction or meridional position of the adjustment factor. As an example, Dr. Rivers[11] noted with both Cambridge men and the Toda tribes the following peculiarities resulting from the method:

> The adjustments from greater to equal tended to give larger measurements than in the opposite direction. . . . The V-H illusion was somewhat larger when the variable was the horizontal than when it was the vertical; about 10.2% in the former case, 6.7% in the latter. . . . "All these discrepancies," says this author, "would be explained if there should exist a general tendency to make the variable line too long when making one line equal to another."

The effects of practice, then, as they developed in the regular procedure of this experiment, it is believed are sufficiently ac-

[10] Dr. Valentine (British Journal Psychology, Vol. V, p. 8), observed the V-H illusion to increase for several subjects as a result of practice, and attributed the matter to the adoption of a more 'mechanical' attitude toward, or a complete yielding to, the *immediate sensory impressions;* and these "sensory impressions" he deemed of a purely retinal sort. These practice effects were among his proofs of a retinal origin of the V-H illusion. But if one accept this theory, then the retina is also solely responsible for the increasing overestimations of all lines in the left half of the field (observed in the work of Jo., Pe., and Ta.), for the equal balance of the right and left halves of a second group, and, further, for *both* an increasing and decreasing series of estimations in the case of still another observer. Practice, then, on this basis proves too much, unless there be a more adequate correlation with retinal facts.

[11] See references, p. 33.

counted for on the basis of the method used. In other words, the subjects have manifested a "mechanical yielding" not to a primary condition of vision, but *to a secondary influence of the experimentation.*

Tests.—A further question remained: Is it possible to overcome the V-H illusion by practice? Mr. Winch[12] reports that with practice in drawing, school children tend to overcome the illusion. In an equal line series of this experiment the phenomenon reached almost a vanishing point for subject Jo. One subject, Hu., was seen to reverse, and three others to increase the usual disparity in the successive series. The problem here is whether or not with continuous practice under uniform conditions accuracy of judgments may be increased, that is, the illusions made to diminish or disappear. There proved to be time for only a single series with a single subject, Ca. The tests were confined to the two lines M 0 and M 90, on which the position of the Var. and St. alternated successively. The time involved was thirty days, with forty judgments at the daily sittings.

Three methods were employed: (1) An abridged normal series, involved merely the "in" and "out" adjustment and the alternate positions of the St. and Var. This was continued daily throughout the course of the tests, even when another procedure occupied a part of the period. (2) In a second series, continuing ten days, the subject was first given "equality" as a norm to which he was to return after a resetting of the Var. (3) For another ten days the method of minimal changes took up a part of the practice period. The adjustable line was moved by stages of one and two millimeters, the subject reporting the point of apparent equality and the first perceptible variation—in either direction—from equality.

Results.—Instead of the hoped for reduction of the illusion or gain in accuracy, there followed these methods merely the settling into fixed habits of judgment. With the Var. at M 0 the illusion became approximately 10%, and at M 90 about 5%, with an average variation of less than a millimeter in any series. Which of the percentages (5% or 10%) is the truer representa-

[12] British Journal of Psychology, Vol. II, p. 220.

tion of the actual illusion as conditioned by the *primary cause,* cannot be said. Both are in close harmony with the data quoted above from Rivers, also that from Wundt pg. 13. Possibly a mean between the two would be our truest estimate of the "primary" facts in this case.

Possibly with younger subjects, such as those reported by Mr. Winch, and also with the kinaesthesis from the hand entering into the practice (as a result of the subject's making his own adjustments), the results might have been different. In Mr. Winch's report, however, the same subjects were not tested at different stages of their practice, but a different group of children for each stage of development. But for this adult, trained, observer, endeavoring to report only the sensory given in each instance, practice in itself has no effect in altering finally the type of his results under any of the conditions here employed. The two type results obtained indicate, as in former series with other subjects, a subjective attitude, possibly of attention, and—something more. The changed attention with the position of the Var. was again insufficient to overcome the illusion in any case, and therefore something more fundamental than was reached by practice effects or attention attitude is indicated.

So far, then, as this experiment affords data upon the subject, practice may be deemed only a *secondary* influence which under given conditions can alter the amount of the various meridional disparities but which does not as yet point to any definite primal cause of those original and persistent disparities that are superior to its influence. It remains for the next section to investigate the basic element in the changing subjective attitude.

5. *The Effects of Attention Attitude*

The preceding analysis of the effects of practice led to an ascription of those results to the objective factor of adjustment, but with the suggested psychic correlate of attention attitude. The purpose of this section is to examine the effects of a voluntary alteration in the direction of the attention, and to correlate such effects with the data of the preceding sections.

Tests[13]

The "norm" for attention (page 9) as given to each subject at the beginning of his work was this: (1) To fixate the center of the field, (2) to think of the St. as the unit of estimation, and (3) to judge when the Var. became equal *to* the St. This, in effect, assigned to the standard line the central, and to the variable a subordinate place in the attention. The problem in the present series is that of testing what results would follow from reversing this attention attitude, that is, from making the variable line itself the focal matter and judging the St. according to it. The final judgment in the former case, in effect, was this: "Now this line at my right [the Var.] is equal to the upper vertical [the St.]"; and in the latter instance, "Now the upper vertical [the St.] is equal to the right horizontal line [the Var.]"

Two series were given: (1) the regular normal, i. e., the attention on the St., and (2) a repetition of the same objective procedure, but with the subjects' attention on the Var. The Var. throughout remained at M o. The observers were Jo., Pe., and Hu. The time was immediately before the close of their two to four quarters' service in the experiment. All the practice effects, then, that have been described, were fully developed.

Results.—Table VII gives the results in full. The following are the principal facts.

Subject Hu.—(1) In the "normal" series, attention on the St., this subject continued to give the negative results that had characterized his work from the beginning of the control tests. For example, the illusions of the upper and lower verticals, this series, were respectively —10.05 mm. and —21.15 mm. (2) With attention on the Var. (M o) the positive illusions, characteristic of his earliest work reappear, not only in the vertical lines but also in the diagonals of the upper field. The overestimations of the two verticals now become 3.2 mm. and 2.15 mm. The increase in the apparent length of the upper vertical, thus, is 13.25 mm., and of the lower, 23.3 mm.

[13] The attention series was brief because coming at the end of the service of busy subjects pressed by their own student work, and because also its apparently high significance was not realized until the evaluation of the data some months later.

Now if the voluntary direction of the attention toward the horizontal line (the Var. in this case) produces the usual positive V-H illusion while the direction of the attention toward the vertical (here the St.) negatives that illusion, then it seems in this case at least, that *the line held in the focus of the attention tends to decrease in its apparent length or to be underestimated with respect to that one more marginally viewed.*

Subject Pe.—(1) In the case of this subject it is the normal series (attention on the St.) that shows the greater variation from the usual normal results in the work next preceding this. The variation, however, is confined to the significant lines M 90 and M 90′ (upper and lower vertical), all other results falling well within the average variations. The illusions for the upper and lower verticals are respectively +18.85 mm. and +12.9 mm. (2) With attention on the horizontal (the Var.) these illusions become respectively +25.8 mm. and +19.45 mm.

Again, as for Hu., the voluntary direction of the attention to the horizontal line results in an increase in the apparent length of both the upper and lower verticals. Here these increases are respectively 6.95 mm. and 6.55 mm. Attention to the vertical does not in this case destroy or reverse the V-H illusion, but it does noticeably diminish its amount. If, then, attention to the horizontal line *increases* its usual *under*estimation with respect to the vertical, or attention to the vertical *diminishes* its corresponding *over*estimation with respect to the horizontal, there is harmony with the results of Hu. in the evidence that *the line held in the focus of the attention tends to diminish in its apparent length, or to appear of less extent than the same line when more marginally attended.*

Subject Jo.—All differences shown by this subject in the two series are well within the average variation of the usual normal series corresponding to this period of his work.

The introspections of the three subjects measurably account for the differences in their results. When the norm for attention was first given, when it was restated in common with all other norm conditions at the beginning of the "Control" tests, and when at last it was emphasized and made the basis of this

final series of those tests, each of the subjects made enlightening remarks. In the beginning, their comments, like those of all other observers, were upon the difficulty of steady fixation at the center. For a time their chief problem was to gain comparative control in this respect.—In doing this they reduced their average variations not only within each single series but also between the "in" and "out" series.—As to the balance of attention between the Var. and St. lines, the subjects were required only to answer *in terms of* the St. that is, to state that the Var. was too long or too short with regard to it. This at first was supposed by the operator to be sufficient guarantee that the attention was chiefly directed toward the standard, as required in the "norm."

But at each of the two restatements of the attention norm this supposition was proved a mistaken one. Jo. commented in each instance that the condition was very hard to fulfill, that he felt sure his attention fluctuated between the two lines and had done so in the other series. In the last tests (Attention series) he was clear in the statement that he could detect no difference in the two attention attitudes required. His results bear him out; no appreciable difference is found in the two series.

Pe. made comments very similar to those of Jo., but in the Attention series apparently his intenser efforts at control were effective upon the first two lines of the group—the upper and lower verticals—for here the amounts of the overestimations are reduced from what they had grown to be with practice to something nearer their averages in his earlier normal series.

Hu. was himself experimenting at this time, in animal psychology, and hence keenly attentive to any changes of conditions; he also had remarkable powers of concentration in any given task. It is therefore not surprising that the change of method here impressed him especially. His comments at each restatement of the norm were in the way of questions to make sure he understood; a knitting of his forehead showed the intensity of his effort to fulfill the requirement.

Now, granted that these observations are true and that the results of this voluntary attention series are valid as a basis

for interpretation of earlier data, then the following seems a plausible account of what had taken place in the general Practice stages.

(1) In the preliminary stage all subjects (like Pe. and Jo.) must have allowed the attention to drift naturally between the two lines compared. (Minor fluctuations in the results, throughout the experiment, *may* have been due largely to such fluctuations of the attention.)

(2) Since in a part of this preliminary period the three subjects were alike in showing an overestimation of all other lines with respect to the Var., the attention must have been more frequently or more strongly attracted by that line than by the St., thus giving to it rather than to the St. the real focal place.

(3) The tendency to overestimate all other lines with respect to the Var., for a time increased with practice in the case of all subjects. (See page 26.) This on the above basis would signify an increased yielding to the involuntary attention drift as influenced by the adjustment. This inference is corroborated by these particulars: (*a*) For Hu. the increase with practice was arrested at an early date. With his first clear understanding of the attention norm (St. focussed), he began to reverse the type of his results. (See Table IV, Ocular Position series.) This reversal, i. e., the negative illusion, continued and increased with practice until in the voluntary attention series the Var. is again focussed. With this the earlier type of results follows. (*b*) For Pe., whose practice was less regular, the increased illusion in the vertical was less marked than in certain other lines. But the very large overestimation noted is unarrested until, in the final Attention series, under stress of renewed urging he shows in the first two lines of the series (M 90 and M 90′) a tendency to smaller disparities more typical of earlier work. And this decrease occurs when the attention supposedly is upon the St. (*c*) For Jo. there was no noteworthy arrest of the tendency to enlargement of the illusion from practice. Apparently whatever was his attention attitude in the beginning continued with increasing effectiveness until practically the last; and this best accords with his introspections. Since these results are in har-

mony with those of Pe. and Hu. when the attention was "adrift," and also in harmony with what the latter evidenced with the voluntary attention upon the Var., we must conclude that the Var. line must have been the controlling influence upon the attention in Jo.'s case also.

(4) All the above is borne out by the fact that in other series, where the position of the Var. was altered, there followed in each case the increased overestimation of lines in the field opposite the Var. If this were due to a stronger "pull" of the attention toward the Var. than toward the St. line (and is there any reason why the opposite, for instance, should be true?) then again it is the line held in the focus of the attention that tends to decreased apparent length in comparison with the one more marginally viewed.

(5) In complete harmony also is the additional fact that for those subjects in whose case the position of the Var. was altered with each successive series, there did not follow with practice an increase in the average amounts of the illusions.

So far, then, the results of the voluntary attention series may be said to corroborate the conclusions of Sec. 5, to the effect that practice results are attributable to a subjective attitude relative to a chance element of method, namely, the objective movement in the variable line.

Comparison with Data of Earlier Experimenters

Rivers,[14] as noted above, points out the indication of *"a general tendency to make the variable line too long when making one line equal to another,"* and the relation of this to the changing amount of the V-H illusion with alteration in the position of the variable. The work of practically any investigator of a similar problem illustrates the same point. There is in this matter perfect accord with the data of this experiment (Part I, Chart I). If there exist also, as evidenced by this voluntary attention series, "a general tendency" to overestimate the line in the margin of the attention relative to that in the focus of the attention, then we must conclude that in all these recorded

[14] See p. 62.

cases the Var. line has thrust itself into the focus and the standard more into the margin, and hence attention, or attention attitude, has influenced the results.

Valentine suggests the greater difficulty of *attending* "to objects in the vertical than in the horizontal periphery, owing to our greater practice with the widely extended horizontal field," as a possible cause of the V-H illusion, but gives no direct proof of this or of his suggested basis for the increase of that illusion with practice. (See footnote, page 62.)

Stevens' experiments[15] offer data the most closely allied with that of the attention series here. He found that peripheral extents were overestimated with respect to similar extents in the focus of vision. Now the focus of visual attention and the focus of the visual field are not *necessarily* the same, but ordinarily they are; likewise with the margins of the two. The identification of the data of this series with that of Prof. Stevens implies that in this experiment *with each attention shift there was a corresponding eye shift.* If the latter may be granted—and it is not discordant with the introspections at least in the earlier series—then there is exact correlation of facts. At any rate we do know (1) that the margin of the visual field (where Prof. Stevens notes the overestimations) is *attended to with greater difficulty* than the focus of that field, and (2) that in this experiment the line left voluntarily in the margin of attention tended to increased estimated length in comparison with the line focalized. To this extent there is undoubted harmony. Upon this basis one may examine the ocular structure for conditions that would render marginal vision different from the focal and inquire if those conditions are greater in extent in the vertical than in the horizontal dimension of the field. For *explanation,* unless one is satisfied with a central—Attention—theory, must push farther than the experiments of this investigation have been able to go.

[15] See p. 12.

Summary of Part III

(1) The phenomena of the normal field are unaffected by the experimental changes introduced in (a) Ocular Position, (b) Bodily Position, and (c) Objective Contour.

(2) Practice does change, and very appreciably in some cases, the amount of meridional disparities. The changes connect themselves closely with those involving the adjustment factor. Practice, however, does not avail, in the given tests, to overcome or appreciably to reduce the illusions.

(3) Attention attitude is effective in altering the type of disparities in the visual field. Apparently this may account for those changes growing out of "adjustment" and "practice," possibly even the minor variations as well.

(4) The specific effect of voluntary attention attitude apparently is to diminish the subjective length of the line focalized relative to a similar line more marginally viewed.

(5) The data of the experiment, as so far reviewed, do not conclusively reveal the structural basis of the phenomena. It is found necessary, therefore, to supplement with facts of histology.

THEORETICAL EXPLANATION. RETINAL STRUCTURE

1. *Summary of Theories*

The oldest explanation of the vertical-horizontal disparity, and kindred illusions, is, according to Wundt,[1] the imagination-judgment theory. This in various of its forms is advocated by Helmholtz,[2] James,[3] and Lipps.[4] The first two suppose the usual allowance made for perspective foreshortening of squares seen in the horizontal plane to be the basis of the habit of over-estimating the height of a square seen in the upright position. Lipps makes the aesthetic judgment the cause of such disparities; that is, the "habit" of *perceiving movement* in lines—a striving upward or erection in vertical extents and a corresponding contraction of the horizontal dimensions of figures—results in the relative over- and underestimations in these directions. The three agree in supplementing the retinal impression with data of a central nature in order to account for the illusion. The contour theory of Külpe[5] assumes that the image of the given figure is supplemented by the influence of additional data from the environment; and thus it also in effect becomes a judgment theory.

Now aside from the fact that the retinal sensory data seem abundantly adequate to account for visual space perceptions, including the meridional illusions, there are other factual evidences that militate against the judgment hypotheses. In the first place, the contour theory seems to lose the case upon experimental grounds; and the aesthetic (?) perception of movements in lines may easily be traced to eye movements, or attention

[1] Die geometrisch-optischen Täuschungen, S. 157 ff.

[2] Handbuch der physiologischen Optik, S. 702.

[3] Psychology, Vol. II, pp. 264.

[4] "Aesthetic Faktoren der Raumanschauung," in Beiträge zur Psych. und Phys. der Sinnesorgane; Festgruss zu Helmholtz.

[5] *Suggested*—Outlines of Psychology, pp. 365-366.

phenomena. In the second place, perspective—even if the observer were not *sure* in giving his judgments that he sees the experimental figure in a plane—is not wholly deceptive. One recognizes a square placed diagonally *as*—a square in the diagonal position. Again, one may see a drawing at will as a plain surface or as tridimensional. But the illusions of the vertical-horizontal type are practically unescapable. Furthermore, it is found that young children and primitive peoples (Todas and Papuans)[6] manifest a larger V-H illusion than do civilized adults. It is difficult to understand how these (especially the savages) can have been confronted with a sufficient number of squares and rectangles (printed pages, carpets, etc.!) to have built up so nice a set of *habits* of judging as the perspective theory of James or Helmholtz presupposes. Such explanations for the illusion are open, finally, to the objection that they ascribe to judgment and habit (factors that are supposed to correct our sense impressions and assist in adaptation to objective realities) a process that is fundamentally misleading.

A second group of theories assumes a relationship between asymmetries of the bulb and the given illusions. As an extension of the Kundt-Hering theory,[7] namely, that of the estimation of the distance between two points by the chord rather than by the arc between their retinal images, there is needed but to presuppose the requisite differences in the vertical and horizontal dimensions of the bulb to account for the V-H illusion along with the illusion of unfilled space [Hering] and the illusion bearing Kundt's name. (See page 12.) But apparently this presupposition is not established by the facts of anatomy. Moreover, both Wundt and Delboeuf show that a space divided by a single point is underestimated with respect to an open space of the same extent, thus:

. . . .

This would apparently invalidate the whole theory of the estimation of space by retinal chords.

[6] See references, p. 33.

[7] Poggendorf's Annalen, cxx, S. 118 ff. Hering, Beiträge zur Physiologie, I, S. 65 ff.

Asymmetry of the lenses, astigmatism, was considered on page 32. In the past it frequently has been suggested, and as often abandoned, as a possible cause of the V-H illusion. Wundt[8] long ago pointed out that (1) astigmatism varies greatly with individuals, is often entirely absent, while the illusion is universal, and (2) compensatory lenses that correct astigmatism do not cause a disappearance of the illusion.

Wundt's own theory, as noted, is built upon the known asymmetries in the size of the muscles moving the eye in the vertical and the horizontal directions. He dismisses the "judgment" theories as not only the oldest, but also the most unscientific of the hypotheses. But it is difficult to see how the blending of sensations from disparate senses (retinal and muscular), as called for in his theory, ever came to be without the activity *at some time* of conscious or unconscious judgment. If this blend or fusion is a conscious, ontogenetic, acquirement, then his is a judgment theory; if it came about phylogenetically, there is left the puzzle of how far Wundt is at this point from being a nativist. Indeed both Wundt and James apparently contradict their general principle of explanation of visual space perception in their accounting for the normal space illusions. The experimental aspect of this discussion has been stated, pages 53-56.

In all the above theories, apparently, nativists and empiricists alike lose sight of the retinal image as a possible factor of close correlation lying directly between the objective extent on the one hand and the subjective estimation on the other.

Recently, however, the advocates of a purely retinal theory have grown in numbers. Witmer[9] ascribes a *part* of the spacial illusions (e. g., filled versus unfilled space) to variation in the degree of the "physiological excitation" of the retina; other illusions, e. g., the V-H, to variation in difficulty of eye movement. Stevens,[10] whose work on foveal and peripheral differences of estimations is so significant of retinal conditions, considers the overestimations he finds in the right cyclopean field

[8] Die geometrisch-optischen Täuschungen.

[9] Analytical Psychology, p. 92.

[10] Psychological Review, Vol. XIX, p. 30.

must be due to "some yet unknown anatomical or physiological condition peculiar to the left corresponding halves of the retinae in consequence of their connection with the left hemisphere of the brain." This, however, does not account for the more significant foveal and marginal differences, or for the vertical-horizontal disparities. At least there is no apparent connection, to the writer's knowledge. Valentine[11] proceeds by a process of elimination (i. e., of muscle strain, of astigmatism, and of aesthetic appreciation) to the conclusion that the retina itself must be the source of the meridional disparities. As to either the physiological condition of the retina, or the "obscure psychological factor at work here," he has no final explanation except to suggest, very aptly, the possibly greater difficulty of *attending* in the vertical than in the horizontal dimension or "that those conditions, whatever they may be, which give rise to variations in the apparent size of objects as seen by different parts of the periphery of the retina, differ from the conditions at the center more in the vertical direction than they do in the horizontal direction."[12]

2. *Retinal Structure*

It is the purpose here to examine the retinal surface, both as to its physical characteristics, or form, and as to its anatomical detail, with a view to discovering what, if any, correlations may exist between the data found and the functional facts revealed by this and similar experimentation.

[11] British Journal of Psychology, Vol. V, p. 327 ff.

[12] Dr. J. W. Hayes finds that, in foveal vision, of two equal luminous bodies in a vertical relation to each other, the lower is frequently judged to be of the greater magnitude. While the correlation of this illusion with definite structure, or with other functions, is not yet evident, this author concludes that its restriction "to foveal vision indicates its dependence on functional and hence on structural peculiarities of this region as contrasted with the rest of the retina." *A Horizontal-Vertical Illusion of Brightness in Foveal Vision,* Psychological Monographs, Vol. XX, No. 1.

James, Stumpf, and Külpe are well known among the older psychologists who "conclude . . . that the retinal impressions are from the first endowed with a spatial predicate"; but they are very slow in ascribing to the retinal impressions the responsibility for the illusions of space.

The maintenance throughout the experiment of the primary fixation at the center of the field makes possible a fairly close approximation of the retinal areas affected in each series.

(1) *Physical Aspects of the Retina.*—Is there anything in the physics of the optical organ that may interpose to prevent uniform correlations between retinal magnitudes and objective magnitudes? In other words, is it or is it not a certainty—as many writers appear to assume—that equal objective extents mean invariably equal retinal extents, no matter in what part of the field, foveal-peripheral or meridional, the image may fall? Such an inquiry must necessarily be faced, whether or not its conclusions aid in explaining the given phenomena of visual space. The question as it is affected by meridional differences, i. e., irregularities of curvature in bulb or lens, has been fairly dismissed in the preceding discussion. But the matter of foveal and peripheral differences has yet another aspect. If the retina were a perfect sphere, and concentric to the nodal point, and the refractive index were identical throughout the eye, then exact equality in size of images from like objective cause, no matter what the direction of its location, might reasonably be expected. But the eye departs from these ideal conditions. The refractive index changes with each angular remove from the line of fixation, and the retina is not a perfect sphere. The completion of the retina would pass through the crystalline lens; the *ora serrata* is about on a plane with the nodal point. The refraction at the margin tends to bend the image back toward the center of the field, while from the forward location of the nodal point arises the physical necessity that the images falling marginally (nearer the node) occupy a less space than those from a like objective extent but impinging upon the central part of the retina.

But, so far from finding in these dioptrical conditions an explanation of the foveal-peripheral differences of vision pointed out by Prof. Stevens and apparently evidenced by this experiment, there is, on the contrary, an added difficulty. The real causal condition—whatever it may be—must be of sufficient

potency not only to produce the overestimations at the margin of the field with respect to the foveal region, but to overcome in so doing the counteracting influence of the diminished sizes of the images at the margin.

(2) *Histology of the Retina.*—The arrangement of the retinal elements is thus stated by Ladd and Woodworth:[14] "In general the rods are more numerous than the cones. The distribution of the two elements is different for different parts of the retina. In the yellow spot [macula] only cones appear, but these are of more slender form and of increased length, so that not less than one million are supposed to be set in a square 1/10 inch; while not far from this spot each cone is surrounded by a crown shaped border of rods. Toward the *ora serrata* the cones become continually rarer."

Apparently, since the slenderness of the cones and their exceeding compactness are mentioned as a peculiarity of the macula and especially of the foveal area, one is to infer that marginally the tendency is toward a general decrease in the number not of cones only but of all retinal elements per unit of area. At least we can be certain that the massing of the *cones* falls in the macula, while a larger and larger proportion of rods prevails towards the margin.

Moreover, since the cones decrease in *length* from the fovea toward the margin, the surrounding or "crown-shaped border" of rods, may be supposed likewise to diminish in this dimension. This is supported by the statement of Gray[15] that the retina "gradually diminishes in thickness from behind forward."

A further differentiation between the marginal and macular structure arises from this peculiar distribution of the rods and cones. This is in the matter of the neural connections. We are told by various authorities that the cones are usually connected singly with one bipolar cell each, while the rods are connected in groups of a half dozen or more to a single bipolar cell.[16] The

[14] Elements of Physiological Psychology, p. 193.

[15] Anatomy, p. 860. (Edition 1893; Pick.)

[16] See Quain: Anatomy, Vol. III. Pt. 2, p. 232. Also Fig. 169, p. 238. Angell: Psychology, Fig. 49, p. 141.

neural equipment, then, of the center of the field is superior to that of the margin.

These details of structure seem sufficient to necessitate *some* differences in focal and marginal space estimation. As a matter of fact, and whether or not there be a cause and effect relationship, the correlation actually found to exist, according to Prof. Stevens' data, is as follows: comparative underestimation accompanies the superior equipment of the central retina, while corresponding overestimations are coupled with the lessened efficiency of the margin.

It is desirable next to inquire the relative extents of the marginal and macular areas in the vertical and horizontal meridians of the retina. Cunningham,[17] and apparently all authorities who mention the matter, state the longest dimension of the macula—the area of compact conal structure—to be the transverse or horizontal diameter. Helmholtz[18] gives the following measurements from Kölliker:

Horizontal diameter of the macula	3.24 mm.
Vertical " " " "	0.81 mm.
Diameter of the fovea centralis	0.18 to 0.225 mm.

Whether the last named dimensions mean that the fovea also is an oval is uncertain; the presumption is otherwise.[19] But clearly the macula is a slender oblate oval, one-fourth as wide as long. This means that the area of closely crowded elements extends about four times as far horizontally as it does vertically, or, that the marginal conditions of structure, whatever they may mean of deficiency or inferiority of equipment, approach more nearly to the center in the vertical than in the horizontal radius. Again, whether or not there be a cause and effect relationship, the actual correlation of the data is as follows: The line having the more extended macula, or superior equipment as to structure, is the one which corresponds to the greatest comparative underestimation in the visual field, namely, the horizontal, while the vertical dimension which shows the widest extent of marginal

[17] Textbook of Anatomy, p. 815.

[18] Handbuch der Physiologischen Optik, S. 37.

[19] Parsons (*An Introduction to the Study of Color Vision*, 1915, p. 9) says: "The foveal region is an elliptical area with the long axis horizontal. The long axis measures about 0.3 mm., the vertical 0.2 mm."

structure likewise corresponds to the visual line of greatest comparative overestimations. This is in entire harmony with the above correlations of general foveal-marginal structure with facts of focal-peripheral vision.

The third inquiry arising is, do there exist also inequalities in the distribution of the rods and cones in the upper and lower vertical or right and left horizontal areas of the retina, such as would correlate equally well with the disparities found in the corresponding parts of the visual field? Further, does the general ovoidal arrangement of elements prevail in the medial and marginal parts of the retina as well as in the macula itself—as would be required for a correlation, on the same basis, with the data of overestimated diagonal meridians? To these questions the histologists consulted give no answer. An inference from a related function is, therefore, all that is available at this point.

(3) *Structure Inferred from Known Function.—Two-Point Acuity.*—Apparently no theorist has been bold enough to suppose that the matter of visual two-point acuity is dependent upon imagination, aesthetic judgment, practical judgment, influence of objective contour, or even of eye muscle strain,—or upon any fact or feature other than that of the retina itself with its peculiar arrangement of elements. If, then, the function of two-point discrimination—or other function peculiar to the retina alone—has been more thoroughly worked out in the various areas of the field than has the minute detail of cone and rod distribution, it seems legitimate to refer to these studies for some inference concerning these further facts of structure so desirable here. At least it may be seen if the two functions of point discrimination and spacial estimation correlate with each other as well as either apparently correlates with the structure itself. It will be the purpose, then, in the following paragraphs to carry forward a dual comparison, namely, that of the two-point acuity data both with the structural detail above cited and with the corresponding data of this experiment.

Sanford[20] says: "The discriminative power of the retina falls

[20] Experimental Psychology, p. 106.

off rapidly in all directions from the *fovea*—more rapidly above and below than in the horizontal direction." There is here an evident correlation with the facts of structure, i. e., with the ovoidal form of the macula and the more extended "margin" in the upper and lower vertical than in the horizontal borders. There is, further, our first indication of an existing correlation between comparative underestimations and a high visual acuity, and, vice versa, between overestimations and a low acuity.

Poschoga[21] found the discriminative power decreased in successive removes from the pole of vision, and certain of his figures show a markedly lower acuity in the upper vertical than in the right horizontal meridian. These facts again correlate the foveal-marginal and vertical-horizontal differences of space with the discriminative differences on the basis named above, as well as with the known facts of structure.

Wertheim[22] has worked out in much detail the problem of

Fig. 7.

After Th. Wertheim: Ueber die Indirect Sehshärfe, Zeitschrift für Psychologie und Physiologie der Sinnesorgane, VII. B., S. 185.

[21] Psychologische Studien, B. VII, S. 384 ff.

[22] Zeitschrift für Psychologie und Physiologie der Sinnesorgane, B. VII, S. 172.

acuity in indirect vision. His observations were made upon his own left eye, and his results—which he says are in harmony with those of numerous investigators whom he cites—are presented in a graph repeated here as Fig. 7. The points on the different meridians having equal acuity are joined by curved lines. The main facts indicated and which he states in his discussion are as follow: The visual acuity diminishes in the upper field most rapidly, somewhat less rapidly in the lower field, still more slowly toward the medial side, and the very slowest laterally (outer side). However, within a radius of some 15° from the pole of the field—the area with which this report is immediately concerned—the curves apparently mark a reversal of this lateral-medial relationship.—That there is a quick descent in acuity from the fovea marginally in stages indicated by the curved lines is shown by the following statement of the proportions. Representing the acuity (*Sehshärfe*) of the center by 1, the first curve drops to 0.333, the second to 0.2, and the third to 0.143, and so on to the outer one, whose acuity is represented by 0.026.

It is further apparent from the diagram that in the function of discrimination the *ovoidal arrangement* of the "zones" *persists from the macular region to the margin of the field.* Since high acuity is generally correlated with number of retinal elements, we have, then, in this functional data a strong indication that the number (or efficiency) of the retinal elements would be found to diminish more rapidly in the lower retina, which views the upper field, than in the upper retina, and, in the extra macular region, more rapidly in the vertical than in the horizontal dimension. In the absence of histological data, which would be extremely valuable at this point, the inference as to structure may be permitted us. On the other hand, there is a clearly marked and unmistakable correlation between the two functions of discrimination and spacial estimations, and in perfect harmony with the fact cited above, namely, that where discrimination is low there is high overestimation and where discrimination is acute there are comparative underestimations. In other words, the acuity chart and the typical field graphs show an inverse relation

as to size of parts. The former has its greatest diameter in the horizontal dimension, its least in the vertical, and its lower vertical extent is greater than its upper, while there is a variation with location in right and left parts. The latter—for the majority of subjects—has its least diameter in the horizontal, its greatest in the vertical direction, is more extended (usually) in the upper vertical radius than in the lower, and is less certain in the relative proportions right and left of the center. The diagonal radii likewise take corresponding medial places between the vertical and horizontal lines in the radial disparities of the two graphs. Furthermore, in passing from the central to medial parts of the field there is shown, in the discrimination chart, a variation of outline indicative of a possible correlation—were the two charts in each instance made for the same eye of the same individual—of the two functions in the corresponding concentric segments, as well as in the larger field outline.

Finally, it is entirely conceivable, from these concentric zones of acuity that the slightest shift of *attention,* with a corresponding eye shift, would tend to alter the position of the images of the given lines relative to the retinal parts, and hence relative to the number or efficiency of the elements affected.

On this basis, then, of structure known from histology and of structure inferred from closely correlated function, it is possible to trace a direct *correspondence* of the peculiarities of meridional space perception with the anatomy of the organ most closely concerned with vision, namely, the Retina.[23]

3. *Detailed Correlations*

The angular extent of the retinal space covered by the normal St. of this experiment was 6° 12′, which approximates the ver-

[23] Wundt (Outlines of Psychology, p. 139) makes an attempt to dissociate the functions here correlated, ascribing the one to the retina, the other to the eye muscles. His basic assertion is that two points, as soon as they are distinguishable at all, "will appear just as far apart in one region [foveal or peripheral] as in the other." This is at variance with Professor Stevens' more recent results. Very simple tests, also, such as passing two pencils, held a short distance apart, from the margin around to the center of the field, cast a doubt upon the statement, and lead one to question if Wundt's utterance is not somewhat dogmatic.

tical limits of the second of the acuity curves of the Wertheim chart. Combining these in the same figure and adding an approximate outline of the fovea centralis and the macula lutea, reduced to the same scale—one-fifth the objective size of the standards—gives a figure upon which may be based a comparison

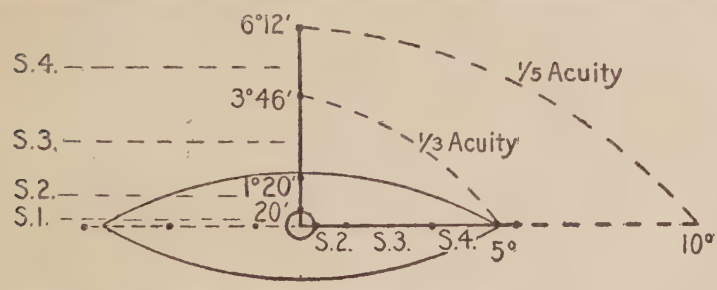


FIGURE 8.—The small circle represents the fovea centralis; the oval, the macula lutea; the solid vertical and horizontal lines are the normal standards of this experiment (the dots indicate the extent of the shorter standards, S. 1, S. 2, S. 3, and S. 4); the broken curves represent the Wertheim lines of acuity. All are reduced to the same scale. The extents of the retinal angles included in the different spaces are indicated in degrees and minutes.

of values. (Figure 8.) Exact mathematical accuracy is not possible, since the functional and histological studies could not be made upon the same eye. Nevertheless, the results of the authorities quoted have been sufficiently verified by others in their field[24] to be accepted as typical for the human eye in general, and to afford a reasonable basis for the comparison of data. It is seen that this entire experiment has been taken up with a very small area in the central part of the field as presented by the Wertheim figure.

(1) *The Vertical-Horizontal Illusion, Normal Standard.*—The radial extent of the normal standard in retinal terms (see page 5) is 1.727 mm. The transverse radius of the macula (½ of 3.24 mm.) is 1.62 mm.; the vertical radius (½ of .81 mm.) is .405 mm. The image of the St. in the horizontal position, then, when the inner end is fixated, overlaps the macula by *.1 mm.;* in the vertical position, the difference is *1.32 mm.* If spacial estimations are to correlate with retinal structure, the

[24] See bibliography cited by Wertheim.

principal surprise here is not that there should be a V-H illusion, but that its percentage should be no greater than it is usually found to be in the normal eye.

It is true that the macula (according to Kölliker) has a width only one-fourth its length—a difference of 75%—whereas the V-H illusion is seldom reported as more than 25% of the St. length. But histology has not answered as to the actual *rate of decrease* of retinal structure or efficiency, in the various radii, beyond the macula. A comparison, then, with the acuity data is more helpful. It will be noted by the chart (Fig. 8) that the image of the horizontal St. of 140 mm. reaches a point measuring about 1/3 the efficiency of the center of the field, while the vertical line of the same length terminates in an area of about 1/5 efficiency. The difference is 2/15—interestingly near the Wundtian ratio of "1/7" in the comparative enlargement of the vertical line over the horizontal. If, then, two-point acuity correlates with the structure of the retinal surface, it seems reasonable to suppose that another function in so close correlation with the acuity data might be equally dependent upon the same anatomical conditions.

(2) *Overestimation of the Diagonal Meridians.*—The fact that the Wundtian graph (Fig. 5) is not a perfect quarter oval, but shows a sudden bend outward from the horizontal line, and the further fact that the graphs of this experiment (the "field types") have very "square" corners, are each in perfect harmony with the former indications of a close inverse correlation between two-point acuity and space estimations. If the same structure *should* be the basis of each of these two visual functions, then the triple correlation as evidenced by the graphs (Chart I, also Fig. 5 and Fig. 8) is as follows: For each successive angular remove of a given line from the horizontal meridian of the retina there follows a decrease in such structural efficiency as marks the macula, a decrease in acuity, and a corresponding increase in the overestimation of the linear extent, until the maximum of these conditions is reached in the vertical line. Indeed, if the structural hypothesis be true, then the Wundtian graph (Fig. 5)

indicates a very tapering oval in the macular form, with perhaps an especially marked prolongation in the horizontal meridian.

(3) *Foveal and Peripheral Differences of Meridional Disparities.*—Figure 8 above indicates that part 1 (S. 1) of the St. corresponds in retinal extent quite closely with the fovea itself; that part 2 (S. 2) in the vertical direction practically reaches the limits of the macular area, and that parts 3 and 4 (S. 3, S. 4) of the same line, accordingly, are outside this area; and that, on the other hand, the corresponding parts 2, 3, and 4 of the horizontal line fall wholly, or almost wholly, *within* the macula.

If, then, Figure 7 is as truly indicative of structure as it is of the function of acuity, the "triple correlation" yet holds, and it is not a matter of surprise that there was found in Part II of this experiment a tendency to increase the percent of the V-H disparity as the St. and Var. lines were moved by successive stages from the center toward the margin of the field. That segment 3 should so often have shown a higher percentage of the illusion than even segment 4 is peculiarly interesting in view of the fact that in M 0 this segment lies *wholly* within the macula and thus may be presumed to have great structural advantage over the corresponding segment which in M 90 lies almost wholly in the extra-macular region. Shifts in the attention, however, might readily vary the results here as well as in segment 1, where the negative illusion is recorded for some subjects and the positive illusion for others; for the tiniest movement of that square one-tenth inch into which one million elements are crowded might vary by several hundreds, or even thousands, the number of elements affected by the given stimulus. Furthermore, there *might* be unique variations in the exact pattern up and down and right and left in the arrangement of those elements in different eyes, and hence individual differences in results. That the percentage, positive or negative, was always high in this central segment is not so significant as might seem, since any appreciable error would be large in proportion to so small a base—7.5 mm. (See Table III.)

The Figure 7 (two-point acuity) as a whole correlates inter-

estingly with the statement of Fischer that the eye has different *"Maasstäbe"* in the different meridians, as well as with the data of this experiment indicative of a variation in the *"Maasstäbe"* (measuring units) in passing from the fovea to the periphery along the various meridians. (It will be noted from the Figure 7 that the acuity curves are not absolutely uniform or parallel. How in this case it can be supposed that the acuity phenomena are due to the retina alone while such closely correlated data must be attributed to another sense, the kinaesthetic, it is not quite clear to the writer. Were the Weber-Fechner law *established* in the phenomena of space estimation, as Münsterberg concludes from most irregular data, then the muscular theory might be expanded to include the phenomena, though it would be unnecessary. But the data of Chodin, and the data of this experiment *seem,* as stated, to evidence a possible *irregularity* in percentage of the illusion with different lengths or segments of the standards. This irregularity, whether a phenomenon of the attention only or an inherent feature of the normal, fixed, conditions, can be reconciled with a purely retinal hypothesis. (See topics 6 and 7 below.)

(4) *Disparities of Upper and Lower Vertical Extents.*—Five of the eight regular subjects of this experiment overestimated the upper vertical meridian with respect to the lower; two others showed considerable variation in the matter; while one, Jo., in 75% of a long series of tests reported the lower field greater than the upper. The Wertheim chart, Fig. 6, agrees (on former basis) with the majority, by showing a higher degree of discrimination in the lower field—viewed by the upper half of the retina—than in the opposite area. If, again, this chart is indicative of the *usual* arrangement of retinal structure and the correlations here cited are valid, then it is to be expected that in the majority of cases, as Delboeuf[25] has reported, the upper field will be seen larger than the lower. We have no direct knowledge of the differences in relative width of the upper and lower parts of the macula; but *if* the two closely correlated visual functions may be *thought of* as dependent upon the same

[25] Page 12.

visual structure, then there is here the double inference that the macula must be narrower in its lower than in its upper extent, as divided by the horizontal line cutting the central point of focal vision. To account for those cases—for example Fischer,[26] and subject Jo. of this experiment—where the lower field is pronouncedly and repeatedly seen larger than the upper, one must suppose either a marked difference of *attention habit* resulting in a more or less fixed ocular position (see Part I, Sec. 2, series 3), or else a primary difference in structural arrangement in the eyes of the different individuals. The fact that the illusion of the figure 8—readily seen by inversion, thus, 8—is common to the race is indicative again of the truth of the Wertheim data and of the general correlations that have been based thereon.

(5) *Disparities in the Right and Left Horizontal Extents.*—The Wertheim graph is of the monocular field, left eye. Within a radius of 15° from the pole, apparently discrimination is greater in the right field—viewed by the temporal retina. Beyond this area the difference is reversed. The experiments of this paper fall within 7° from the pole. The line halved by the subjects of Kundt,[27] who showed an overestimation in the outer field (nasal retina), had an angular extent on either side of the pole of about 9°. It is not surprising to find superior discrimination in the temporal retina in the first removes from the center. The color fields have for some observers a much wider extent in the temporal than in the nasal retina. The temporal sides of the two retinae attend to the section of space immediately in front of the individual, that is, in the binocular field, and to the finer objects of near vision. Beyond the area of distinct binocular vision, it is the nasal retina which guards the outer horizontal margins, and *it* is provided with the wide areas of acute vision.

[26] Fischer not only saw the lower vertical greater than the upper, but he overestimated the inner with respect to the outer half of a given radius. The fact that he was one-eighth shortsighted raises the question if the second phenomenon may not in his case be due to dioptrical rather than to structural conditions. (See page 76.) At any rate, the data is no more easily explained by the muscle-strain hypothesis, for instance, than by a retinal theory.

[27] Page 12.

But the linear extents used in the present experiment nowhere test the differences in spacial estimation in parts of the extreme margin of the field. The correlations are confined to the central area, where there is nothing contradictory in the indicated structural arrangement (Fig. 7) to the statement of Kundt that in monocular vision the outer part of the objective field is overestimated with respect to the inner. Indeed there is again a proof from the work of these two authors (Kundt and Wertheim) that there must be a correlation of the two functions of discrimination and spacial estimation, the finer discriminations being coördinated with the comparative underestimations.

On this basis one should expect a nice balance in binocular vision between the right and left halves of the field. Such a balance or equality of estimations was approximated by several subjects of the shorter series of this experiment, in which the position of the variable line was altered in successive tests. Nevertheless, in those series affording the nearest possible elimination of the adjustment factor (see "Equal-Line" series, Part I, Sec. 2) there persisted still some individual differences in the characteristics of right and left fields. Reports from other investigations are alike indicative of individual differences in this respect. Stevens[28] says the right field is overestimated with respect to the left. Münsterberg[29] asserts the left is overestimated with respect to the right. Külpe[30] says a distance to the left "generally" appears greater than a distance to the right. In the "Eight-equal-line" series of the present work, four of the five subjects saw the right horizontal line as the shortest of the radii, yet two of these later indicated a reversal of this right and left difference.

As to the persistent individual differences, one of two possible hypotheses must needs be adopted to complete the correlation with the discrimination, and the inferred structural, data. There must be presupposed the existence either of a more persistent attention attitude on the part of the subjects concerned, or, an

[28] Psychological Review, Vol. 15, p. 69 f.; Vol. 19, p. 1 f.
[29] Beiträge zur Experimentellen Psychologie, Heft 2, 125.
[30] Outlines of Psychology, p. 359.

individual difference in the arrangement of the retinal elements. These hypotheses are respectively considered in paragraphs "7" and "6" below.

(6) *Individual Differences in Field Types.*—The marks of individuality have in large part been mentioned in paragraphs 4 and 5 above. Yet that there are distinctly individual combinations of those variations is shown quite conclusively in series E, Chart I, as well as in the Equal-line series, Chart II. Further individual traits are to be found in the diagonal eccentricities of the graphs of Pe. and Ta., for instance, and in the peculiar outlines of the medial and central field graphs of Py., Chart III. Furthermore, the variant results of other investigators, as above shown, are indicative of marked individuality of *some kind* on the part of the different observers.

Now the fact that in Figure 7 the lines of acuity are not always parallel, or in perfect conformity, is very suggestive of possible irregularities of retinal pattern in the arrangement of the epithelial structures, the rods and cones. And if such irregularities exist why should there not be individual variations in this as in any other feature of the human organism? Why should not individual retinae vary as much in pattern as do the lines of the skin, for instance, that give individuality to a thumb print.[31] There are ways in which all thumb prints are alike, there are ways in which each thumb print must be forever unique. May this not, conceivably, be equally true of the retinae?

It is possible to conceive, also, that momentary causes, or at most *attention habit,* might sufficiently account for many of the phenomena of individual differences. In many instances of differences in results among experimenters this doubtless is a true explanation. Certainly the unstable features of this experiment

[31] Parsons (*Color Vision,* pg. 10) says: "There is physiological evidence that the rod free area [macular region] varies in size in different individuals."

Ruediger (*Archives of Psychology,* No. 5.) finds marked indication of individual variation in the acuity field types. That he does not, however, correlate this phenomenon with existing variations in the amount of the V-H illusion for the same subjects may very possibly be due to the fact that the latter experiments were very brief and made with free rather than constant fixation, which would leave in doubt the retinal areas explored.

—e. g., the practice types of Hu., Chart V—must be accounted for in some such manner. But to ascribe to attention habit those features that persist through all changes—as, for instance, the same subject's overestimation of the right field with respect to the left, of the upper with respect to the lower, and the equally marked characteristics of other subjects—surely this is equivalent to reducing habit to a phylogenetic thing, to structure itself.

Granted that there is a structural basis for innate or fixed habits, might not that structure be in the asymmetries of the ocular muscles? Is there not, without any presumption, a correlation here? Such an inquiry is worthy of analysis. There is unquestionably an inverse correlation between the general arrangement of the ocular muscles and the directions of over- and underestimations in the visual field. Some peculiarity of muscle attachment, for instance, might be thought of as a possible basis for the individual peculiarities in general field outline. But that such an explanation could be extended to meet the variations, or non-conformities, of the interior outlines (e. g., Py., Chart III) is scarcely conceivable. A structural correlation upon a retinal basis seems to the writer far more plausible as an hypothesis.

A further functional fact lending weight to the theory of individual peculiarities in retinal structure is the matter of the color fields. It would indeed be unusual to find two individuals the outlines of whose color charts coincided.—Certainly "muscle strain" is not responsible here.—Why, then, may it not be possible that in other functions, for example space perceptions, the retinae should be responsible for individual differences?

(7) *Attention Data.*—Attention to a line probably means one of two things. Either there may occur the usual involuntary eye shift in the direction of the attention shift, or, conceivably, an increase of neural energy in the marginal retinal parts attending. Either of these conditions would tend to increase the efficiency of the parts brought to bear upon the stimulus. Certainly attention could *not decrease* that efficiency.

Now we have seen in Part III, Sec. 5, of this experiment,

that voluntary attention to a line tended to decrease its subjective extent in comparison with the line left correspondingly in the margin of attention; also, that whenever there was a condition that would tend to attract the involuntary attention toward any particular line, corresponding results followed. If focal attention means, then, in any sense, focal vision, or a tendency toward it, then the data here correlates perfectly with all that is reviewed in the paragraphs above; that is, the greater underestimations are found to accompany the greater acuity, the greater retinal efficiency, and the comparative overestimations, accordingly, are found in the regions of inferior structure and function. This means, a shift of the eye toward a line brings it nearer to the focus and leaves the other line correspondingly toward the margin, or, the change in innervation would mean for the line clearly attended a similar advantage over the lines less attended.

Now that either of the supposed retinal changes positively occurred with changes of the attention in this experiment, cannot positively be demonstrated, since there is yet no X-ray machine for photographing fluctuations in neural activity, and unfortunately no photographs were made of the eye movements during the process of this experimentation. The presumptive evidence in favor of the existence of the eye movements, however, is strong. In the first place, no fact is more general or more generally known, to the common man and the psychologist, than that of the impossibility of *perfect* or unwavering fixation at a given point, or the tendency for the eye to yield to the involuntary or reflex "pull" in the direction of whatever tends at a given instant to draw the attention. Second, the introspections of the subjects were most clear upon this point, especially in the beginning of their work—when their average variations were exceedingly high. Finally, it remains for those who object to the propositions on which these correlations rest, to demonstrate to us—for only the truth is sought—just what does take place with fluctuations of the visual attention.

One such objection again is anticipated, namely, that though "eye shift" should be granted, there is a corresponding change in muscular strain, and that even a controlled *tendency* to eye

shift would mean the greater strain of the "tendency to movement," which Wundt says is as potent in results as movements actually performed. Some facts of the experimental data make this objection at first appear plausible. Part II was, in a sense, a study of marginal attention. It was there found that the V-H illusion increased—or tended to increase—as the stimuli were moved correspondingly nearer and nearer to the margin. If this general V-H disparity be due to an original difference in the strain of the muscles that move the eyes in these two directions, it is conceivable that this difference in strain would increase with the distance traversed, or with the strain of the "tendency" to traverse the given distance. But again in Part III, Sec. 1, there was given an objective field in the *extreme margin* as to actual muscular strain, and there followed no results such as would be required by the muscle-strain theory. It is only when the lines are marginal as to the retina (Part II) that significant changes take place. Aside from this, in the Attention series (Part III, Sec. 5) it was when the horizontal strain —or movement—apparently was greatest—i. e., with the attention on M 0—that the illusion increased, while with attention to the vertical (M 90)—increasing, if anything, the movement or movement tendency in that direction—the illusion decreased. This scarcely seems in correlation with the muscle-strain theory.

We have little knowledge of the minute exactness of the nerve supply of the ocular muscles, such as would enable us to form a conception of what particular combination of their activities would increase or decrease the total strain. We do know a few details of the retinal areas; so much, in fact, that we are sure a movement of one-tenth of an inch shifts the one million cones of the central fovea toward the favored visual object, and a much slighter movement must suffice to shift some hundreds or even thousands of these elements in the given direction. In each instance the less attended line moves correspondingly toward the less favored areas as to structure. The phenomena of focal-peripheral attention (Part III, Sec. 5) apparently are reducible, then, to a correlation with fovea-marginal structure. The presumptive evidence in favor of a retinal explanation for merid-

ional illusions of space is therefore enhanced rather than diminished by the data of the Attention series.

The phenomena of certain of the supplementary tests are most readily accounted for upon the basis of attention attitude, or attention fluctuations, as here explained. See data of "monocular vision," "elevation of the head in primary vision," and "undeveloped mentality," Part I, Sec. 2, series (1), (3) and (5).

The variable data of the experiment as a whole, as well as the more fixed or persistent features of the "field types," are thus found capable of harmonious correlation with retinal structure as it is known from histology and as it is inferred from facts of acuity.

Data from Other Experiments

The psychological principle of Attention, as determined or controlled by fixed retinal structure and by variations in eye position, seems ample, further, to account hypothetically at least for the widely divergent factual data from other investigators cited in preceding pages.

It would be interesting, at least, to know the "attention attitude" of the subjects of Münsterberg and of Stevens, as well as of other authorities whose results are contradictory. Certainly in our right handed reading, writing, and other tasks, we come to attend ordinarily more to the right field than to the left. This might easily lead to the general attention habit that accords with Külpe's statement that "generally" the left field is seen larger than the right.

One of the interesting (and correlating) instances from Lipps may be cited. He states (see page 6) that the mere conception of *any* one of the sides of an equilateral triangle as the *base* leads to an underestimation of that line and a corresponding overestimation of the remaining two. A careful observer will doubtless confirm the statement. But the careful observer will also note that the conceiving of one of the three lines as the base is attended by a *focalization* of the line so conceived. There follows, then, such disparity between the base and sides as correlates perfectly with the usual characteristics of focal and marginal vision, or focal and marginal attention.

Without further detail it may be recalled (see page 29) that in this experiment—with apparently like objective experimental conditions—there were found as widely divergent individual differences as any recorded differences in results of other investigations. If in this case of the uniform conditions it seems possible, may it not be still more probable that in experiments of unlike conditions, the true explanation of the individual variations may rest ultimately upon attention attitude, as controlling and controlled by the relationship between the objective given and the peculiar retinal configuration?

CONCLUSION

If it be asked how the correlations above recited *explain* the meridional disparities in visual space, the answer is, very frankly, that this the writer can no more say (with assurance) than she can state in other than hypothetical terms how the retina transmutes wave lengths into color sensations. The fact of the correlations is the one thing apparently indicated by this study. And somewhat paradoxical these correlations at first may seem. One readily accepts the association of, for instance, two-point acuity with structure; but to correlate relative underestimations of space with areas of clarity of vision, keenness of discrimination, and superiority of neural equipment, and the corresponding overestimations with regions of less efficiency and inferior structure, would scarcely occur to one did not such relations recur again and again in the experimental and other factual data.

But if it has been conceivable to the minds of men that the inverse relation between spacial estimations and muscle structure is meaningful, why should it be a thing impossible to suppose some harmony exists, some meaning resides, in the close relationship between these spacial perceptions and the retina itself? How this relationship came to be or the function it may serve in the economy of nature are questions upon which we may form only what seems to us a reasonable surmise. Mere difference in number of elements—rods and cones—in the macula and the margin of the field, and—because of the shape of the macula—in the vertical and horizontal meridians of the field, *might* in itself be sufficient to account for all disparities. Might it not be that the greater the number of elements brought to bear upon a given object the smaller, the more insignificant, that object would appear, while in the marginal areas of fewer elements mere indistinctness might be translated into a vague bigness? A pencil held between thumb and finger, or by two fingers, is a vaguer object as to size than when grasped by all the fingers at once.

Is there any reason why, in last analysis, *differences in ease of visual attention*—dependent upon relative number or efficiency of elements—may not be sufficient bases for all differences in meridional and foveal-peripheral space?[1]

But turning from the question of how the differences are mediated, one is confronted by the further inquiry of what economy of vision is served by the unequal distribution of structure and function in the different areas of the retina. Is there any need or purpose demanding that the macula should be wider in its upper than in its lower extent, or that it should be four times greater in its transverse than in its vertical diameter?—It seems possible that adaptations to environmental conditions may have required or even occasioned just such an arrangement. The lower objective field, viewed by the upper retina, is the more detailed and critical for life interests, and hence may demand greater clarity of vision, greater ease of attention, finer discrimination, and finally a provision for seeing detailed parts in *smaller compass* than is necessary in apprehending the upper field. The upper objective field is more remote, is less fraught with details of immediate concern, and hence may be thought of as fairly provided for by the less acute vision of the lower retina, if there be not even an aid to far vision in the comparative overestimations of this region. But the panorama of the earth's surface stretches out with its infinite detail in the *horizontal* rather than in the vertical direction. There is less call for attention in the up and down direction, especially up. The seeking of food and the avoidance of danger demand that we attend not only straight forward, immediately before us, but far to the right and to the left, and, further, that there should be minute, clear vision, with *compression* of details into small compass—or comparative underestimations. Here Nature apparently has been lavish in her provision. Not only do the functions and the form of the single macular region contribute to these ends, but we have two eyes, and these are horizontally placed. Again, the

[1] Külpe, fertile in suggestions, says: "It [the V-H illusion] might also be ascribed to the far greater accuracy of judgment (keenness of vision) in the horizontal direction." Outlines of Psychology, p. 365.

peculiar refractive power of the cornea greatly widens vision. And, finally, there is a beautiful adaptation of the ocular muscles[2] to the giving of readiest *attention* in the fields most fraught with sudden emergencies. Thus the monocular field, the binocular field, and the whole field of regard tend to follow harmonious outlines of the oblate oval type.[3] In addition to this we see in the tendency to horizontal compression (underestimation) a further device for extending the visual grasp in that critical dimension of the field. That in a given circular area (such as delimited by this experiment) the vertical meridian should be comparatively overestimated, seems but an accident attending the more important matter of the horizontal compression, the bringing of a wide range of horizontal details into the area of clear vision. Since this is seen (page 76) not to depend upon dioptrical conditions, since there is no evidence that it is automatically connected with eye movements (quite the contrary) and since there is a difference in retinal structure *corresponding* to differences in space estimations, does it not seem reasonable to conclude, until we shall have further light from better investigations, that the retina itself is the ample physical correlate of meridional disparities in the visual field? That part of the brain which "comes out to see" apparently, then, is the chief determinant of the forms that shall be perceived.

One final question arises, namely, what is the bearing of the

[2] May it not be that the true correlation of the asymmetries of the ocular muscles with the facts of vision is found just in this, namely, the extension of the convenient oblate form of the field of vision to the wider outlines of the field of regard? That the direction the eye takes in traversing a line is a cue to hand movements, or other bodily adaptations, is undoubted. But that this is a correlation that must be learned and can be unlearned is evidenced by the young child's inverted script, by the experiences of mirror drawing, and by the more common experiences of the dressing table with its single and double mirrors. That there is a further feeling in the muscles that decides, for example, the visual aspect or form of the figure 8, when common sense is saying, "I *see* it, I image it so," is an unsustained assumption. Neither by common experience nor by experimental evidence does it seem apparent that muscular strain is any more essential to visual space judgments than to "the voluminousness we ascribe to pain," or to any other sensations of a disparate character. (See Külpe's Outlines of Psychology, p. 371, Sec. 5.)

[3] See Figure 4.

data of this experiment upon the theories as to the broader aspects of general space perception? Here again only a modest opinion, not an authoritative response, can be given. It seems to the writer that if the meridional illusions are inherent in retinal structure neither nativist nor empiricist need do violence to his general theory in accounting for these disparities. They come to be in the same way that other space perceptions come—through an interpretation—of *some kind*—of SENSORY data. How far visual space perception approaches an act of *judgment* or of *reason,* how far it may be merely and purely a *sensory given,* is a question for the philosophers. That something akin to judgment enters into our general space interpretation we are led to believe from the fact that the retinal image is smaller than either its objective counterpart or its subjective interpretation. Again, while the area of the whole retinal field stimulated varies little from time to time, one's conception of the space included varies enormously. The image of Niagara is not larger than that of one's own door yard or of the corner of a hall bedroom. If this same corner of a room be decorated with a portrait of Niagara, of a perspective sufficiently hypnotic, it may give the same impression of immensity as that gained from the original of the portrait. What has been termed *judgment* possibly is involved here. A second consideration is that size and distance cues seem to be acquired, not native. A child sees a "colt" from a car window; the father sees in the same object a horse at a distance. The former *attends* solely to the central object of her interest; the latter attends not to that object only, but to the whole field, with its *distance cues* which he has learned through experience. The child's interpretation we term perceptual, the father's judgmental. Yet, in last analysis, what is the act of judgment in this case? Is it not made up solely of a wider and richer *sensory attention?* What has experience given to the father that the child has not yet acquired? Has it not merely increased his power of minute, detailed attention to the data of the whole field? The addition of a new object in the field of view—a human figure at the foot of the Niagara

gorge, a boat or a jut of land in an expanse of sea—immeasurably increases our conception of immensity. What has happened? Nothing except that we have been given a more familiar (sensory) measuring unit. The judgment, as James says of experience, does not make space out of nothingness, it "must be given some grist to grind." The "grist" in this case must be the measuring units, the distance cues, plus the complicating element of variation of retinal structure in the several radii of the field. It is the former that makes up the total aspect or "bigness" of the whole, while the latter determines the variation in outline form, or occasions the apparent meridional disparities of the field; for a given objective "unit" has been found (see Part II, (summary) to have a varying value according as it stimulates one or another of the retinal parts. *Sensory reality,* sensory *attention,* seems, then, the basis of our space judgments, whether of the "normal" or of the so-called "illusory' 'type.

Finally, the only contention of this paper is that it is possible to conceive of the meridional disparities of the visual field as reducible ultimately to retinal structure on the one hand, and to a simple act of visual attention on the other. There is no attempt at disproof, as in Münsterberg's early work, of the existence of the transcendental. The *mind* may perceive—*attend*—as through an open window. But if that window be oval as to structure, the picture must necessarily be oval.

GENERAL DESCRIPTION OF CHARTS AND TABLES

So far as practicable the lettering and other symbols are the same in corresponding charts and tables. The *A*, for instance, in each refers to the first normal series for any subject (or for any series following the normal order of positions for the St. and Var.). The *A'* indicates a later series of the same order (or, if so stated, an *average* of certain features of the A series). In the charts the practice graph, *A'*, is superposed by a broken line, upon the A graph of the earlier data. The same combination for showing practice effects is made in graphs B, C, and D, for subjects Ba., Py., and Ki. The small digits in parentheses, under the graphs, indicate the number of the series upon which the data are based, and thus render evident the amount of practice intervening between any two series represented.

Graphs

The plan of constructing the graphs is as follows: The eight radii are simultaneously represented, reduced to one-tenth their actual length. The over- or underestimation of each is indicated by placing a dot in the extension of the line at a distance from the end (plus or minus) corresponding to one-half the actual amount the Var. (represented by a broken radial line) was lengthened or shortened to give subjective equality in each case. The joining of these dots produces an approximate picture of the subjective "field" of each observer, though the lines for convenience, are straight instead of curved. This further marked divergence in the drawing is also to be noted, namely, that, as indicated by the above scale, the errors of judgment, both positive and negative, are exaggerated to five times, or 500% of, their proportional amounts. All charts are upon the same scale, but in graphs B, C, and D, of Chart I, for subjects Jo. and Pe. a dotted line indicates a reduction of the data to the common basis of M 0, for the greater ease of comparison with the A' series. (Such reduction of the data was made in all cases to obtain the averages entering into the E series of graphs and tabulation.) In Chart III, the lengths of the two shorter standards, used for comparing the smaller field areas with the "normal", are indicated by heavy dots in the different M's, and the corresponding graphs (*C*, "central"; *M*, "medial") are inserted within the "norm", *N*. Again, in these smaller graphs the over- and underestimations are exaggerated 500%.

Tables

In all tables the first numerical column, "90, 90', 45, 45'," etc., represents the meridional positions of the standard with relation to the right horizontal radius (M 0), which, in the normal procedure, is the variable. In the column of italicized letters, the *a, b, c,* and *d* represent angular distances (45°, 90°, 135°, and 180°, respectively) of the St. from the actual Var. of the given series. The letters are primed when the distance is below or to the left of the Var. The data column gives the amount in millimeters (unless percentage is indicated) of the exact over- or underestimation (the latter shown by a minus sign) of the given meridian with respect to the variable line of that particular series—or the amount the Var. actually exceeded the length of the St. when the two were pronounced subjectively equal. These results are the averages of a "double series", or a total of twenty judgments, for each meridional position of the St. in each series. The final column, with the figures 1 to 8, given in some of the tabulations, shows the respective *order* of magnitude of the overestimations, or of the apparent length of the respective radii.

TABLE I.—FIELD TYPES. (St., 140 mm.)

Subject:	Series:	A		A′		B		C		D		E	
Jo.	90 *b*	7.9 mm.	5	28.95mm.	2	*b* 20.25mm.	2	*d* 5.1 mm.	2	*Var.*	5½	*b* 15.92mm.	2
	90′ *b′*	12.6	1	38.95	1	*b′* 21.4	1	*Var.*	4	*d* 5.7 mm.	3	*b′* 18.86	1
	45 *a*	8.5	4	24.45	4	*c* 16.74	4	*c* 7.75	1	*a* 0.0	5½	*a* 14.59	3
	45′ *a′*	9.55	3	12.3	6	*c′* 17.85	3	*a* — .2	5	*c* 5.8	2	*a′* 11.29	6
	135 *c*	7.25	6	23.9	5	*a* 12.1	5	*c′* 3.3	3	*a′* 2.35	4	*c* 12.76	4
	135′ *c′*	12.	2	28.05	3	*a′* 7.1	6	*a′* — 1.5	6	*c′* 7.5	1	*c′* 12.64	5
	180 *d*	3.35	7	11.5	7	*Var.*	8	*b′* — 3.3	7	*b′* — 2.05	7	*d* 3.89	7
	0	*Variable*	8	*Var.*	8	*d* 1.15	7	*b* — 3.75	8	*b* — 6.8	8		8
Pe.	90 *b*	23.35mm.	4	24.85mm.	3	*b* — .35mm.	4	*d* 7.85mm.	2	*Var.*	3	*b* 15.66mm.	2
	90′ *b′*	22.5	5	18.25	5	*b′* — .75	5	*Var.*	3	*d* 2.55mm.	2	*b′* 14.02	4
	45 *a*	4.85	6	8.3	6	*c* 6.15	2	*c* — 1.85	4	*a* — 8.2	7	*a* 8.19	6
	45′ *a′*	3.65	7	8.0	7	*c′* 6.25	1	*a* — 9.05	7	*c* — 1.0	5	*a′* 7.91	7
	135 *c*	33.5	1	40.1	1	*a* — 3.4	6	*c′* 14.35	1	*a′* — .35	4	*c* 18.97	1
	135′ *c′*	30.8	2	29.9	2	*a′* — 5.5	7	*a′* — 5.9	6	*c′* 8.7	1	*c′* 14.97	3
	180 *d*	26.55	3	21.2	4	*Var.*	3	*b′* — 2.45	5	*b′* — 2.8	6	*d* 13.27	5
	0	*Var.*	8	*Var.*	8	*d* — 9.1	8	*b* —11.5	8	*b* —11.2	8		8
Hu.	90 *b*	8.4 mm.	1	— 9.1 mm.	6	*b* — 4.9 mm.	6	*d* 1.25mm.	7	*Var.*	6	*b* —10.1 mm.	6
	90′ *b′*	— 1.5	7	—15.85	8	*b′* — 9.95	8	*Var.*	8	*d* — 3.25mm.	8	*b′* —11.65	8
	45 *a*	5.0	3	— 2.6	2	*c* 13.15	1	*c* 18.25	1	*a* 7.1	2	*a* 2.09	1
	45′ *a′*	4.5	4	— 5.65	4	*c′* 9.25	2	*a* 3.4	5	*c* 5.5	3	*a′* — 3.76	3
	135 *c*	5.3	2	— 4.45	3	*a* 2.1	4	*c′* 9.55	3	*a′* .25	5	*c* — 5.02	4
	135′ *c′*	— 1.6	8	— 8.25	5	*a′* — 8.1	7	*a′* 2.45	6	*c′* — 1.55	7	*c′* —10.75	7
	180 *d*	— .3	6	—11.0	7	*Var.*	5	*b′* 7.7	4	*b′* 2.55	4	*d* — 7.71	5
	0	*Var.*	5	*Var.*	1	*d* 7.3	3	*b* 12.85	2	*b* 7.4	1		2

Ba.	90	*b*	9.42mm.	4	15.7 mm.	1	*b*	14.0 mm.	2	*d*	10.9 mm.	1		*Var.*	5½	*b*	10.06mm.	4
	90′	*b′*	12.75	3	6.55	2	*b′*	11.3	4		*Var.*	4	*d*	7.45mm.	3	*b′*	7.25	6
	45	*a*	3.35	6			*c*	13.8	3	*c*	2.9	2	*a*	0.0	5½	*a*	8.25	5
	45′	*a′*	7.32	5			*c′*	14.75	1	*a*	— .35	5	*c*	10.5	1	*a′*	12.74	2
	135	*c*	21.2	1			*a*	6.35	6	*c′*	.6	3	*a′*	2.	4	*c*	11.22	3
	135′	*c′*	20.17	2			*a′*	9.3	5	*a′*	— .9	6	*c′*	9.3	2	*c′*	14.16	1
	180	*d*	3.67	7	2.15	3		*Var.*	7	*b′*	— 7.75	7	*b′*	— 8.75	8	*d*	.19	7
	0		*Var.*	8	*Var.*	4	*d*	— .45	8	*b*	— 9.9	8	*b*	— 8.4	7			8
Py.	90	*b*	15.07mm.	2	8.5 mm.	1	*b*	7.7 mm.	4	*d*	2.6 mm.	3		*Var.*	7	*b*	7.95	5
	90′	*b′*	11.17	6	2.2	3	*b′*	9.17	3		*Var.*	6	*d*	6.97mm.	2	*b′*	8.65	4
	45	*a*	12.8	4			*c*	7.7	5	*c*	— 1.72	7	*a*	1.57	6	*a*	6.77	6
	45′	*a′*	12.55	5			*c′*	10.9	2	*a*	4.37	2	*c*	7.95	1	*a′*	11.02	1
	135	*c*	16.3	1			*a*	3.77	6	*c′*	6.85	1	*a′*	2.75	4	*c*	9.59	3
	135′	*c′*	13.47	3			*a′*	12.52	1	*a′*	1.72	4	*c′*	6.75	3	*c′*	10.79	2
	180	*d*	9.6	7	4.15	2		*Var.*	8	*b′*	.9	5	*b′*	1.77	5	*d*	2.96	7
	0		*Var.*	8	*Var.*	4	*d*	.07	7	*b*	— 5.37	8	*b*	— 3.42	8			8
Ki.	90	*b*	14.17mm.	2	14.1 mm.	1	*b*	2.8 mm.	4	*d*	5.0 mm.	1		*Var.*	1	*b*	7.96mm.	1
	90′	*b′*	3.27	6	3.65	2	*b′*	5.92	2		*Var.*	2	*d*	— 7.87mm.	7	*b′*	3.27	2
	45	*a*	6.25	5			*c*	6.55	1	*c*	— 5.72	8	*a*	— 6.35	5	*a*	2.62	4
	45′	*a′*	— 3.07	8			*c′*	4.67	3	*a*	— 4.45	5	*c*	— 8.57	8	*a′*	— .42	8
	135	*c*	11.02	3			*a*	— 2.45	7	*c′*	— 4.17	4	*a′*	— 3.6	3	*c*	2.63	3
	135′	*c′*	15.92	1			*a′*	— 2.97	8	*a′*	— 5.45	6	*c′*	— 2.1	2	*c′*	1.29	5
	180	*d*	10.82	4	2.35	3		*Var.*	6	*b′*	— 3.12	3	*b′*	— 6.3	4	*d*	.72	6
	0		*Var.*	7	*Var.*	4	*d*	2.42	5	*b*	— 5.57	7	*b*	— 6.6	6			7
Ca.	90	*b*	17.45mm.	1	13.95mm.		*b*	11.45mm.	2	*d*	10.3 mm.	1		*Var.*	2	*b*	8.74mm.	1
	90′	*b′*	13.6	2			*b′*	7.35	6		*Var.*	5	*d*	— 1.45mm.	4	*b′*	3.81	5
	45	*a*	8.35	6			*c*	11.9	1	*c*	7.0	3	*a*	— 2.65	5	*a*	5.34	3
	45′	*a′*	11.7	3			*c′*	10.7	3	*a*	.25	4	*c*	7.8	1	*a′*	6.55	2
	135	*c*	8.6	5			*a*	7.85	5	*c′*	8.3	2	*a′*	— 2.8	6	*c*	4.42	4
	135′	*c′*	7.15	7			*a′*	6.2	7	*a′*	— .15	6	*c*	— .85	3	*c′*	2.02	6
	180	*d*	10.25	4				*Var.*	8	*b′*	— 3.95	8	*b′*	— 9.65	8	*d*	— 1.9	8
	0		*Var.*	8			*d*	10.5	4	*b*	— 1.95	7	*b*	— 4.3	7			7

TABLE II. EQUAL LINE SERIES.

A. Comparison of Other Meridians with Right Horizontal.

Subject:	Hu.		Ta.		Jo.		Be.	
90	9.45 mm.	1	3.1 mm.	5	1.4 mm.	5	15.2 mm.	1
90′	—4.64	8	4.5	4	9.6	1	13.5	3
45	—2.6	6	2.5	6	1.2	6	.8	7
45′	3.85	2	1.3	7	4.0	3	10.3	5
135	2.15	3	5.9	2	1.5	4	13.1	4
135′	—1.9	5	7.6	1	9.4	2	14.5	2
180	—3.15	7	5.4	3	.4	7	9.0	6
0		4		8		8		8

B. Comparison of Opposite Pairs of Equal Lines.

Subject:	Hu.	Ta.	Jo.	Be.	Pe.
Upper vs. Lower Vert.	7.4 mm.	— .6 mm.	.3 mm.	.2 mm.	1.8 mm.
Right vs. Left Horiz.	3.6	—5.1	.3	—10.7	—6.0
Rt. Up. vs. Lft. Lo. Diag.	2.5	—4.7	—3.2	—11.8	—3.5
Lft. Up. vs. Rt. Lo. Diag.	2.	5.6	—.5	10.6	4.0

C. Comparison of Eight Meridians Simultaneously Exposed.

Subject:	Hu.		Jo.		Pe.		Ca.		Ki.		Ki. (C′)	
90		8	8.5 mm.	1	3.0 mm.	5½	3.0 mm.	1+	6.2 mm.	1	5.5 mm.	1
90′	5.0 mm.	3	6.5	2	3.3	4	3.0	1+	1.3	6	1.3	6
45	4.0	4	6.0	3	1.5	7	2.0	4+	2.0	4½	2.0	4½
45′	3.0	6	3.0	7	3.0	5½	1.5	7	2.0	4½	2.0	4½
135	3.5	5	4.5		4.0	2	2.0	4+	5.0	2	5.0	2
135′	1.0	7	4.5		3.5	3	3.0	1+	.1	7	.1	7
180	8.5	1	4.5		7.0	1	2.0	4+	3.0	3	3.0	3
0	8.0	2		8		8		8		8		8

TABLE III. Part 1.—LENGTH OF STANDARDS VARIED

Series A. (Var. at M o.)— Absolute Values.

Subjects:	Ba.			Py.			Ki.			Ca.		
	N	M	C	N	M	C	N	M	C	N	M	C
St. length:	140 mm.	85 mm.	30 mm.	140 mm.	85 mm.	30 mm.	140 mm.	85 mm.	30 mm.	140 mm.	85 mm.	30 mm.
90	15.7 mm.	8.3 mm.	2.0 mm.	12.4 mm.	—2.1 mm.	—2.8 mm.	14.1 mm.	4.1 mm.	.7 mm.	17.5 mm.	11.2 mm.	5.8 mm.
90′	6.5	7.2	2.5	8.6	.7	.2	3.7	1.9	.45	13.0		
45	3.3	3.1	1.5	9.5	1.5	—2.1	2.0	2.5	.5			
45′	7.3	7.4	1.9	10.	4.0	—1.5	— 1.2	3.1	.9			
135	18.2	15.0	5.0	11.	2.5	—1.3	5.4	4.4	1.2			
135′	16.1	16.1	5.5	11.2	— .4	.1	8.1	3.2	.7			
180	2.2	4.9	.4	6.4	.1	—2.6	5.6	1.7	2.3	10.3		
0												

Relative Values.

Subjects:	Ba.			Py.			Ki.			Ca.		
	N	M	C	N	M	C	N	M	C	N	M	C
St. length:	140 mm.	85 mm.	30 mm.	140 mm.	85 mm.	30 mm.	140 mm.	85 mm.	30 mm.	140 mm.	85 mm.	30 mm.
90	11.2%	9.8%	6.7%	8.9%	—2.4%	—9.2%	10. %	4.8%	2.3%	12.5%	13.2%	19.3%
90′	4.7	8.4	8.3	6.1	.8	.7	2.6	2.2	1.5	9.7		
45	2.3	3.6	5.	6.7	1.7	—7.	1.4	2.9	1.6			
45′	5.2	8.7	6.3	7.1	4.7	—5.	— .8	3.6	3.			
135	13.	17.6	16.7	7.8	2.9	—4.3	3.8	5.2	4.			
135′	11.5	19.	18.3	8.0	— .5	.3	5.8	3.7	2.3			
180	1.5	5.8	1.2	4.6	.1	—8.5	4.0	1.9	7.7	7.3		
0												

Series E. (Average of 4 Positions of the Var.)—Absolute Values.

Subjects:	Ba.			Py.			Ki.			Ca.		
	N	M	C	N	M	C	N	M	C	N	M	C
St. length:	140 mm.	85 mm.	30 mm.	140 mm.	85 mm.	30 mm.	140 mm.	85 mm.	30 mm.	140 mm.	85 mm.	30 mm.
90	11.2 mm.	6.4 mm.	1.12 mm.	8.2 mm.	— .2 mm.	— .7 mm.	7.9 mm.	2.5 mm.	—1.9 mm.	11.2 mm.	5.9 mm.	1.5 mm.
90′	5.1	3.6	1.15	6.8	1.7	.1	3.3	— .4	—1.8	3.8		
180	.6	.2	— .4	2.5	—1.2	— .6	.7	— .9	—1.	— 1.9		

Relative Values.

Subjects:	Ba.			Py.			Ki.			Ca.		
	N	M	C	N	M	C	N	M	C	N	M	C
St. length:	140 mm.	85 mm.	30 mm.	140 mm.	85 mm.	30 mm.	140 mm.	85 mm.	30 mm.	140 mm.	85 mm.	30 mm.
90	7.9%	7.5%	3.7%	5.8%	— .23%	—2.3%	5.7%	3. %	—6.3%	7.9%	6.9%	4.9%
90′	3.6	4.3	3.8	4.8	2.	.2	2.3	— .5	—6.	2.7		
180	.4	.3	—1.3	1.8	—1.4	—2.1	.5	—1.1	—3.3	—1.35		

TABLE III, Part 2.-

Subject:	Ba.				Py.			
	St. 1.	St. 1-D. 1.	St. 1-D. 2.	St. 1.-D. 3.	St. 1.	St. 1-D. 1.	St. 1-D. 2.	St. 1.-D. 3
0	.....	.....	.....	.....	.....	.....	.....	.....
90	7.8%	9.7%	11.0 %	10.2%	3.6 %	3.2 %	5.8 %	8.5
90′	4.1	4.9	3.46	1.1	3.3	2.2	3.9	5.6
180	1.2	1.8	2.18	2.4	.57	.03	1.03	1.8
	St. 2.	St. 2-D. 1.	St. 2-D. 2.		St. 2.	St. 2-D. 1.	St. 2-D. 2.	
0	.....	.....	.....		.....	.....	.....	
90	7.4%	10.5%	12.5%		5.92%	7.58%	2.5 %	
90′	4.9	6.4	7.4		2.87	.83	1.5	
180	1.2	1.4	3.2		.02	— .46	.48	
	St. 3.	St. 3-D. 1.			St. 3.	St. 3-D. 1.		
0	.....	.....			.....	.....		
90	4.46%	14.4%			.73%	—3.5%		
90′	— .43	2.8			4.73	—1.6		
180	—5.01	— 3.7			—5.57	—2.5		

TABLE III, Part 3, *a*.

Subject: Ba.						
Series		St. 1 (140)	S. 1 (7.5)	S. 2 (22.5)	S. 3 (55)	S. 4 (55)
A	0	.....				
	90	11.21%	4.66%	7.33%	7.73%	17.45%
	90′	4.68	—14.	15.77	20.58	18.36
	180	1.53	—15.3	6.66	8.09	6.45
A′	0	.....				
	90	13.2 %	—31.33%	13.1 %	14.9 %	16.8 %
	90′	8.25	.44	— 5.4	8.06	4.1
	180	5.42	—10.44	— 9.63	9.2	5.86
E′	0	.....				
	90	7.8 %	—25.4 %	14.4 %	12.5 %	10.2 %
	90′	4.1	—10.2	2.8	7.4	1.1
	180	1.2	—10.2	— 3.7	3.2	2.4

Part 3, *b*.

		St. 1 (140)	S. 1 (7.5)	S. 2 (22.5)	S. 3 (55)	S. 4 (55)	*Sum of parts (140)*
A	90	*15.7 mm.* *11.21%*	.35mm. .25%	1.65mm. 1.17%	4.25mm. 3.03%	9.6 mm. 6.8 %	*15.85mm.* *11.25%*
A′	90	*18.53mm.* *13.2 %*	—2.35mm. —1.68%	2.96mm. 2.11%	8.2 mm. 5.85%	9.27mm. 6.62%	*18.08mm.* *12.9 %*
E′	90	*11.04mm.* *7.8 %*	—1.91mm. —1.36%	3.25mm. 2.3 %	6.9 mm. 4.92%	5.65mm. 4.03%	*13.89mm.* *9.89%*
	90′	*5.79mm.* *4.13%*	— .77mm. — .55%	.64mm. .46%	3.99mm. 2.85%	.64mm. .46%	*4.5 mm.* *3.22%*
	180	*1.68mm* *1.2 %*	.77mm. .55%	— .84mm. — .6 %	1.83mm. 1.3 %	1.33mm. .95%	*3.09mm.* *2.2 %*

eries E'.

Ki.				Ca.			
St. 1.	St. 1-D. 1.	St. 1-D. 2.	St. 1.-D. 3.	St. 1.	St. 1-D. 1.	St. 1-D. 2.	St. 1.-D. 3.
4.73%	5.9 %	8.45%	6.47%	6.51%	5.7%	8.9%	8.82%
—1.43	— .44	.33	—1.67				
—1.07	— .5	.57	1.47				
St. 2.	St. 2-D. 1.	St. 2-D. 2.		St. 2.	St. 2-D. 1.	St. 2-D. 2.	
.....							
3.55%	5.57%	8.83%		8.8%	7.8%	5.62%	
—1.35	.35	2.38					
—1.48	— .58	— .83					
St. 3.	St. 3-D. 1.			St. 3.	St. 3-D. 1.		
.....							
—2.95%	—1.38%			9.0%	5.7%		
—7.3	—3.15						
—2.03	.87						

Subject: Py. *a.*

		St. 1 (140)	S. 1 (7.5)	S. 2 (22.5)	S. 3 (55)	S. 4 (55)	Sum of parts (140)
A	0	.....					
	90	8.85%	—33.6 %	— 1.92%	1.22%	11.45%	
	90'	6.12	—11.3	4.66	1.63	8.0	
	180	4.58	—26.6	— 2.44	4.9	9.36	
A'	0	.....					
	90	4.07	— 6.	— 6.8	.07	14.6	
	90'	2.47	—29.11	— 4.37	—2.61	.07	
	180	2.15	30.22	—14.96	.91	2.74	
E'	0	.....					
	90	3.6	9.8	— 3.5	2.5	8.5	
	90'	3.3	23.8	— 1.6	1.5	5.6	
	180	.57	24.4	— 2.5	.48	1.8	
				b.			
E'	90	*5.06mm.*	.74mm.	— .79mm.	1.39mm.	4.68mm.	*6.02mm.*
	90	*3.61%*	.53%	— .56%	.99%	3.34%	*4.3 %*

Subject: Ki. *a.*

A	0	.....					
	90	8.75%	2.0 %	2.44%	11. %	12.54%	
	90'	2.1	8.0	— .66	6.72	10.84	
	180	— 1.96	6.0	9.33	6.36	11.45	
A'	0	.....					
	90	11.73	—13.3	2.5	10.1	16.5	
	90'	4.85	— 1.33	—7.7	4.57	10.34	
	180	4.39	—15.77	1.78	.64	6.	
E'	0	.....					
	90	4.73	—15.86	—1.38	8.83	6.46	
	90'	— 1.43	—18.9	—3.15	2.38	— 1.67	
	180	— 1.07	—10.8	.87	— .82	1.47	
				b.			
E'	90	*6.62mm.*	— 1.19mm.	—3.1 mm.	4.86mm.	3.56mm.	*4.13mm.*
	90	*4.73%*	— .85%	—2.21%	3.47%	2.54%	*2.95%*

Subject: Ca. *a.*

A	90	12.46%	39.3 %	14.66%	10.17%	3.63%	
A'	90	11.73	7.7	8.8	10.1	11.6	
E'	90	6.51	13.86	5.7	9.8	8.82	
				b.			
E'	90	*9.12mm.*	1.04mm.	1.3 mm.	3.09mm.	4.85mm.	*10.28mm.*
	90	*6.51%*	.74%	.93%	2.2 %	3.46%	*7.33%*

TABLE IV. OCULAR POSITION, OR POSITION OF EYES IN SOCKETS VARIED.

	Normal	Looking Down 30°	Looking Up 30°	Looking Left 30°	Normal	Looking Right 30°	Normal
				Hu.			
90	8.85 4	7.2 4	2.7 4	—6.2 7	—1.65 5	— 2.13 5	— 5.82 6
90′	1.95 7	.57 7	— .4 7	—4.37 6	—4.82 7	—10.55 8	— 8.02 7
45	9.8 3	9.15 3	5.47 1	— .32 4	2. 2	1.75 2	.65 1
45′	6.7 5	3.77 6	2.2 5	.75 1	—2.02 6	— 5.85 7	— 3.6 4
135	16.1 1	11.9 1	3.07 3	.1 2	2.05 1	4.17 1	— 3.7 5
135′	13.65 2	10.47 2	3.27 2	— .35 5	1.22 3	— .02 4	— 3.42 3
180	4.7. 6	5. 5	—1.9 8	—8.9 8	—4.9 8	— 2.92 6	—10.1 8
0	8	8	6	3	4	3	2
				Ta.			
90	42.22 3	57.9 4	59.65 4	56.75 4	65.0 4	64.84 4	68.95 4
90′	35.65 5	50. 5	55.2 5	52.52 5	56.67 5	47.35 5	57.75 5
45	14.35 6	17.02 6	28.82 6	18.65 7	21.15 6	23.12 6	17.37 6
45′	10.7 7	16.5 7	19.8 7	18.95 6	19.05 7	11.02 7	14.22 7
135	58.55 1	80.72 1	94.52 1	88.55 1	92.55 1	92.1 1	88.72 1
135′	51.52 2	71.87 2	86. 2	71.5 2	72.02 2	84.77 2	78.05 2
180	41.9 4	61.12 3	70. 3	65.12 3	70.07 3	76.17 3	64.75 3
0	8	8	8	8	8	8	8
				Pe.			
90	22.68 4			17.35 5	22.75	24.5 4	32.75
90′	20.52 5			26.42 4	24.85	16.2 5	37.45
45	13.47 6			12.0 6		10.25 6	
45′	6.91 7			7.85 7		7.15 7	
135	36.92 1			26.97 3	33.5	32.6 1	
135′	26.87 2			34.97 1	30.35	31.7 2	
180	24.92 3			33.8 2		27.8 3	
0	8			8		8	
				Jo.			
90	9.9 6	26.92 3	21.47 3	25.47 3	28.65 3	22.25 3	23.2 3
90′	19.17 2	27.35 2	30.57 1	27.4 2	32.67 1	28.95 1	32.4 1
45	11.45 5	18.5 5	15.1 5	21.37 5	21.0 5	14.22 6	20.95 4
45′	11.5 4	16.2 6	15.22 4	12.72 7	17.9 7	15.57 5	14.9 6
135	12. 3	21.82 4	15.02 6	24.67 4	26.92 4	20.45 4	19.9 5
135′	20.62 1	29.55 1	28.42 2	30.35 1	29.62 2	26.35 2	28.45 2
180	4.3 7	13.55 7	13.75 7	20.66 6	18. 6	11.15 7	13.65 7
0	8	8	8	8	8	8	8

TABLE V. BODILY POSITION, OR POSITION OF HEAD VARIED

Subject Hu.

	Normal		Reclining Left		Reclining Right		Head Inverted	
90	—12.4	7	—12.36	6	—11.66	6	—17.05	7
90′	—11.35	6	—12.76	7	—14.6	8	—19.6	8
45	— 5.65	3	— .12	2	1.59	1	— 4.5	2
45′	— 3.85	2	— 3.21	3	— 5.8	3	—12.45	4
135	— 5.87	4	— 5.2	4	— 8.7	4	—12.1	3
135′	— 7.1	5	—11.2	5	— 9.2	5	—15.85	5
180	—12.5	8	—12.9	8	—12.3	7	—16.75	6
0		1		1		2		1
			Pe.					
90′	20.52	5	21.	5	21.54	5	13.15	4
90	22.68	4	21.04	4	13.02	4	11.65	5
45	13.47	6	9.25	6	3.06	7	— .95	7
45′	6.91	7	2.61	7	4.78	6	— 2.05	8
135	36.92	1	32.	2	25.2	1	34.95	1
135′	26.87	2	32.14	1	22.55	3	25.2	2
180	24.92	3	22.94	3	23.5	2	22.3	3
0		8		8		8		6
			Jo.					
90	23.2	3	29.02	1	20.91	2	21.25	4
90′	32.4	1	26.44	3	23.2	1	27.4	1
45	20.95	4	17.61	5	10.75	7	24.	3
45′	14.9	6	14.51	7	12.2	6	14.7	6
135	19.9	5	17.34	6	20.5	3	20.3	5
135′	28.45	2	26.7	2	20.45	4	24.8	2
180	13.65	7	20.8	4	12.61	5	13.5	7
0		8		8		8		8

TABLE VI. TYPICAL PRACTICE STAGES.

WITH ALSO TYPICAL RESULTS OF THE "IN" AND "OUT" ADJUSTMENTS OF THE VARIABLE.

(Overestimations in mm. of the Vertical with respect to the Horizontal line.)

Series:		1st.		4th.		27th.	
		mm.	mm.	mm.	mm.	mm.	mm.
Ta.	O	1.2±2.64	(9.25 Av.)	26.0±2.	(25.15 Av.)	63.6±1.52	(63.55 Av.)
	I	17.3±3.24		24.3± .9		63.5± .4	
		4th.		10th.		18th.	
Hu.	O	4.4±4.7	(7.1 Av.)	11.4±1.12	(10.5 Av.)	9.9± .92	(9.8 Av.)
	I	9.8±2.24		9.6±2.08		9.7±1.44	
		22nd.		24th.		39th.	
Hu.	O	—7.0± .8	(—5.4 Av.)	— 2.5±1.5	(—2.35 Av.)	—7.2± .85	(—7.35 Av.)
	I	—3.8±2.16		— 2.2±1.65		—7.5±2.25	
		1st Nor.		17th.		48th.	
Jo.	O	6.2±1.52	(7.3 Av.)	26.8±2.56	(26.05 Av.)	24.3±2.84	(24.65 Av.)
	I	8.4±1.28		25.3±1.44		25.0±1.	
		1st Nor.		19th.		30th.	
Pe.	O	10.4±1.1	(23.35 Av.)	25.1±1.68	(23.2 Av.)	16.2± .77	(16.25 Av.)
	I	36.3±2.2		21.3±1.75		16.3±1.0	
		1st.		58th.			
Ba.	O	4.8±1.84	(12.4 Av.)	17.0±2.5	(16.75 Av.)		
	I	20. ±2.		16.5±1.0			
		1st.		61st.			
Py.	O	4.7±4.76	(9.95 Av.)	4.5±1.6	(4.9 Av.)		
	I	15.2±1.84		5.3±1.04			
		1st Nor.		6th.		38th.	
Ki.	O	14.1±1.72	(18.05 Av.)	10.6±3.32	(10.3 Av.)	17.8±2.16	(16.05 Av.)
	I	22.0±2.8		10.0±4.8		14.3±2.36	
		1st Nor.		2nd (Var. left)		14th.	
Ca.	O	10.6±2.7	(17.45 Av.)	13.2±3.3	(11.45 Av.)	15.4±1.36	(14.85 Av.)
	I	24.3±4.4		9.7±2.16		14.3± .96	

TABLE VII. THE DIRECTION OF THE ATTENTION ALTERED.

(St. = M 90; Var. = M 0.)

Subject:	Hu.		Pe.		Jo.	
Attention on:	St.	Var.	St.	Var.	St.	Var.
90	—10.05mm.	3.2 mm.	18.85mm.	25.8 mm.	21.15mm.	20.8 mm.
90′	—21.15	2.15	12.9	19.45	17.1	19.75
45	.35	1.85	11.35	8.75	15.9	18.15
45′	— 6.4	—3.45	1.2	1.0	11.35	11.15
135	— 1.75	2.05	27.1	26.55	20.05	21.0
135′	—13.5	—4.8	21.0	24.55	23.8	24.5
180	— 8.2	—7.55	20.25	18.95	14.15	16.6

CHART II. Equal Line Series.

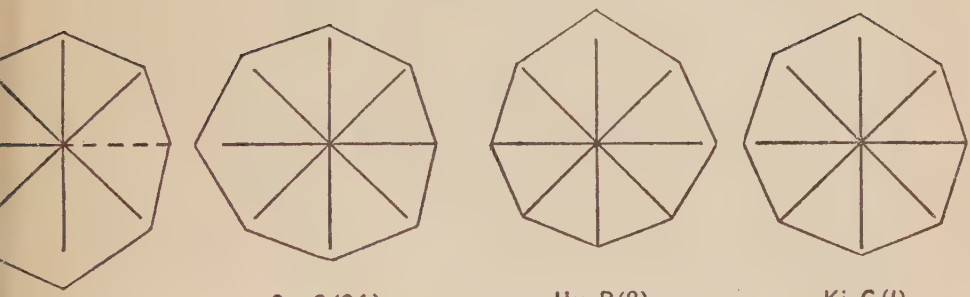
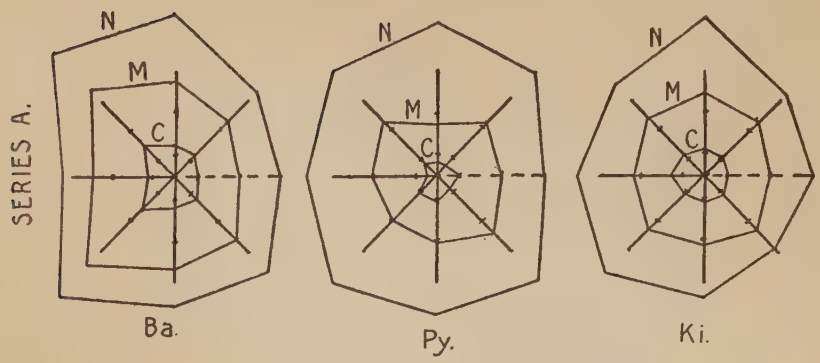
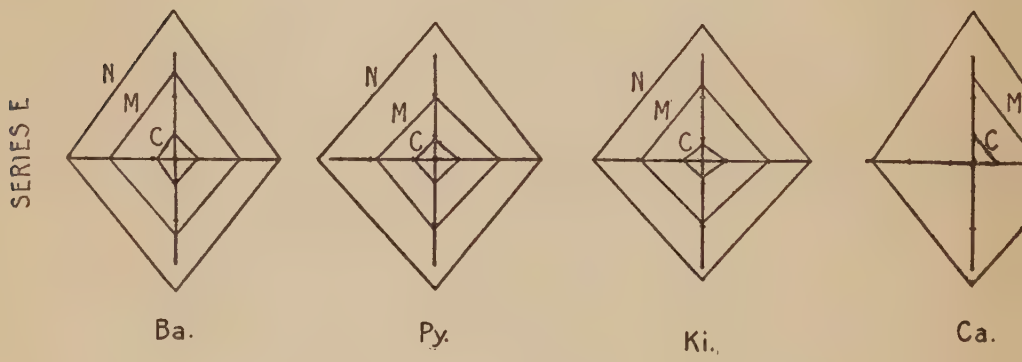


CHART III. Length of Standards Varied.





Part 2.

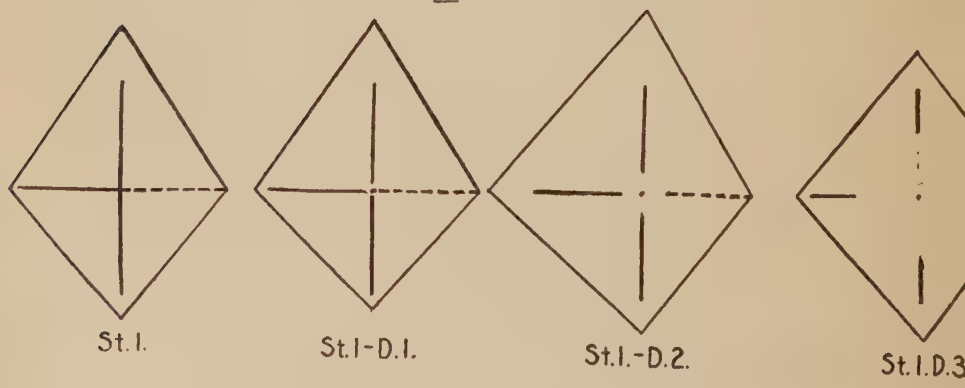


CHART IV. Bodily Position Varied.

Reclining Left | Reclining Right | Head Inverted

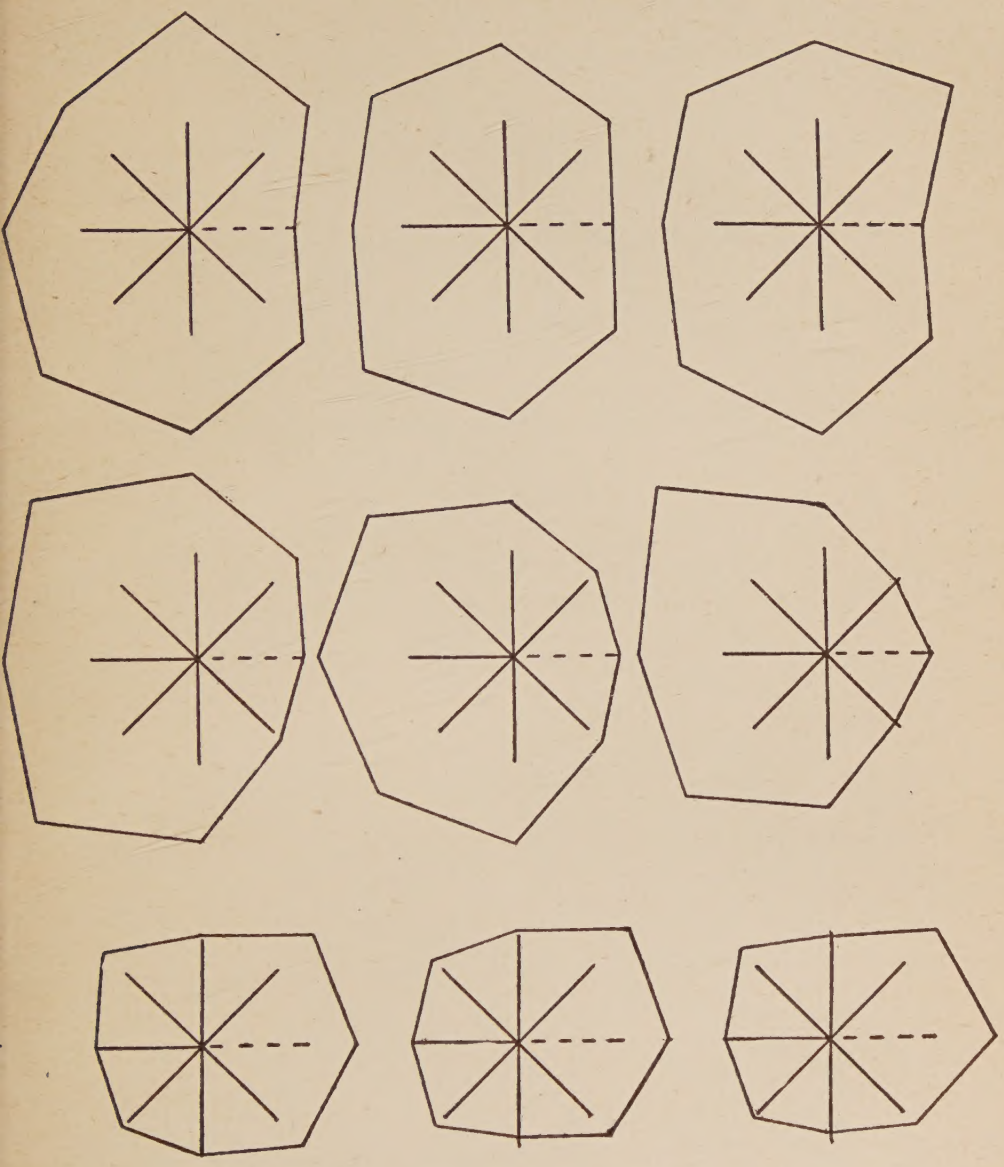
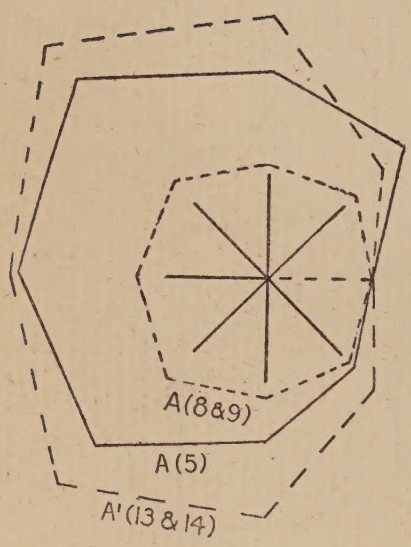
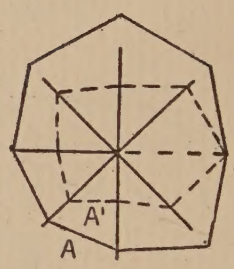


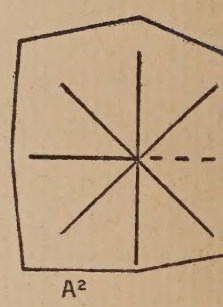
CHART V. Practice Effects



Ta.



Hu.



Hu.